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Tipo Doc.: *Doc. Type:*	REPORT					N° DRD: *DRD N°:*	NA
N° Doc.: *Doc. N°:*	**RICSYS-RP-CGS-020**	Ediz.: *Issue:* **1**		Data: *Date:*	**15/01/2007**	Pagina *Page* **1**	Di *Of* **49**
Titolo : *Title :*	ECAL THERMAL CONTROL SYSTEM DESIGN REPORT						

	Nome & Funzione *Name & Function*	Firma *Signature*	Data *Date*
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File: RICSYS-RP-CGS-020_iss1.doc

REGISTRAZIONE DELLE MODIFICHE / *CHANGE RECORD*			
EDIZIONE *ISSUE*	DATA *DATE*	AUTORIZZAZIONE *CHANGE AUTHORITY*	OGGETTO DELLA MODIFICA E SEZIONI AFFETTE *REASON FOR CHANGE AND AFFECTED SECTIONS*
1	15/01/2007		First Issue

LISTA DELLE PAGINE VALIDE / *LIST OF VALID PAGES*									
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1. SCOPE

This document describes the ECAL thermal control system design and thermal model [chapters 4 to 6]
The thermal requirements are recalled, and the thermal control system is presented in its main components (radiators & tape, heaters, MLI, thermal filler).
The thermal model is presented.

In addition, we present the correlation activities of the ECAL Thermal Mathematical Model (TMM) and Geometrical Mathematical Model (GMM). [chapters 7,8,9,10 and 11].

Test data were acquired during the Thermal Vacuum Cycling/Thermal Balance test held at Terni, and reported in RD1. The thermal model is briefly described, and the correlation criteria are recalled.
Correlation data and sensor locations are reported. The main steps of the correlation activities are reported, and the final correlated model is presented.

Flight predictions with the correlated model are presented.

2. DOCUMENTS

2.1 APPLICABLE DOCUMENTS

AD#	Doc Number	Issue	Date	Rev	Title
1	AMS02-TN-004-CGS	5	02/03/2005	n/a	Preliminary thermal requirement for internal AMS02 interfaces
2	I/020/03/0	n/a	14/05/2003	n/a	Allegato tecnico-manageriale CGS al contratto AMS02/RICH/TOF/ECAL

2.2 REFERENCE DOCUMENTS

RD#	Doc Number	Issue	Date	Rev	Title
1	RICSYS-RP-CGS-019	1	12/10/2006	/	ECAL THERMAL VACUUM TEST REPORT
2	RICSYS-RP-CGS-015	2	7/03/2005	/	ECAL THERMAL ANALYSIS REPORT
3	RICSYS-MI-CGS-013	n/a	13/06/2006	n/a	Minute of meeting: Definition of the ECAL QM configuration, responsibility and schedule
4	NCR-RICSYS-CGS-C-018	n/a	16/09/2006	1	NCR – Temperature sensor readings overwritten during TV test
5	RICSYS-SB-CGS-006	1	10/05/2004	n/a	ECAL TRASYS/SINDA MATHEMATICAL MODELS

3. REQUIREMENTS

3.1 TEMPERATURE REQUIREMENTS

The following temperatures are assumed as design limits for the ECAL PMTs

Operating Range:	-20°C ÷ +40°C
Non Operating Range:	-30°C ÷ +50°C

In the extreme hot orbits the detector can be switched off, in order to eliminate the internal heat dissipation and to decrease the temperatures at the PMT level The total time the detector can be switched off MUST NOT EXCEED the 5% of the total mission duration; this estimate has to be performed in the nominal conditions for the ISS (realistic combination of environmental conditions, and most probable attitude, the Minimum Propulsion Attitude)

The allowed temperature range for the pancake is: -40° C ÷ +65°C

3.2 SHORT-TERM TEMPERATURE STABILITY

A stability of 7°C is required over the orbital period (on the PMT)

3.3 TEMPERATURE GRADIENTS

Temperature uniformity between pancake (lead+ fibers + glue) and aluminum structure is requested, in order to avoid thermal induced stresses. Up to 10°C of temperature difference are allowed.

4. THERMAL CONTROL CONCEPT

The ECAL thermal control concept is based upon passive rejection of heat dissipation by radiators to deep space, while limiting the heat rejected to the other AMS-02 subdetectors

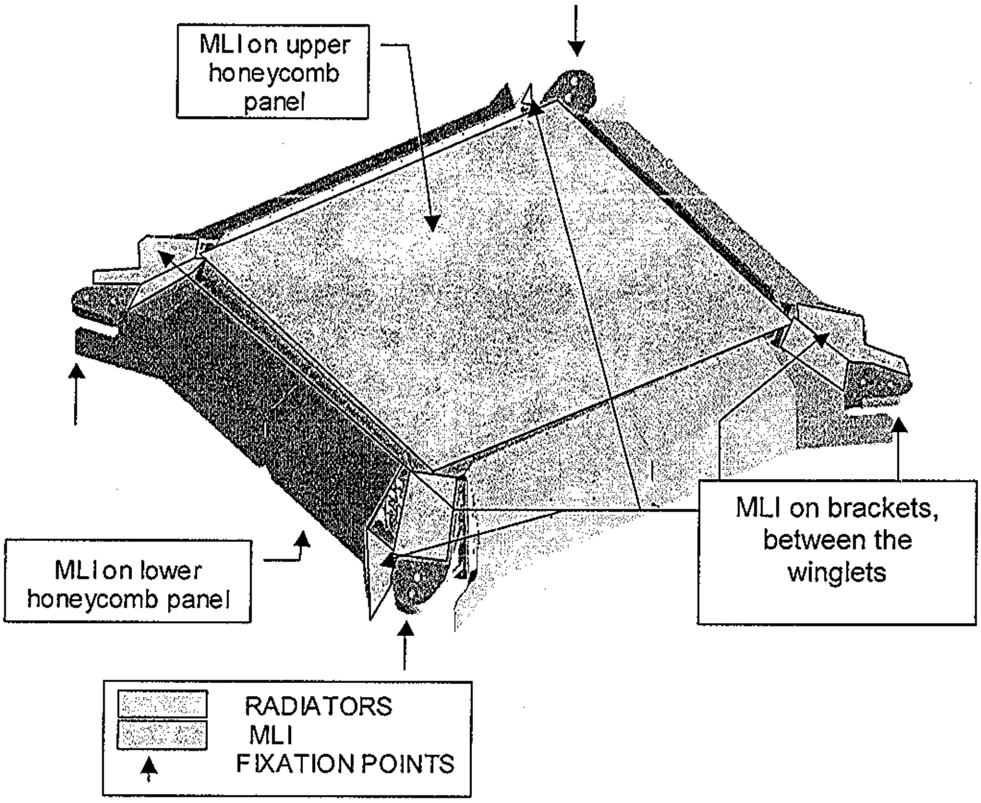


Fig. 4-1: ECAL Thermal control concept, Radiator and MLI locations and fixation brackets.

4.1 RADIATORS

Aluminum alloy panel radiators have been foreseen to reject all the dissipated heat Their position is shown in Fig 4-1.

Each radiator is bolted on the back panel, an aluminum panel hosting the PMTs, at the top and bottom edges.

The radiator aluminum panel thickness is 2 mm. The current dimensions of radiators are shown in the next figures and table:

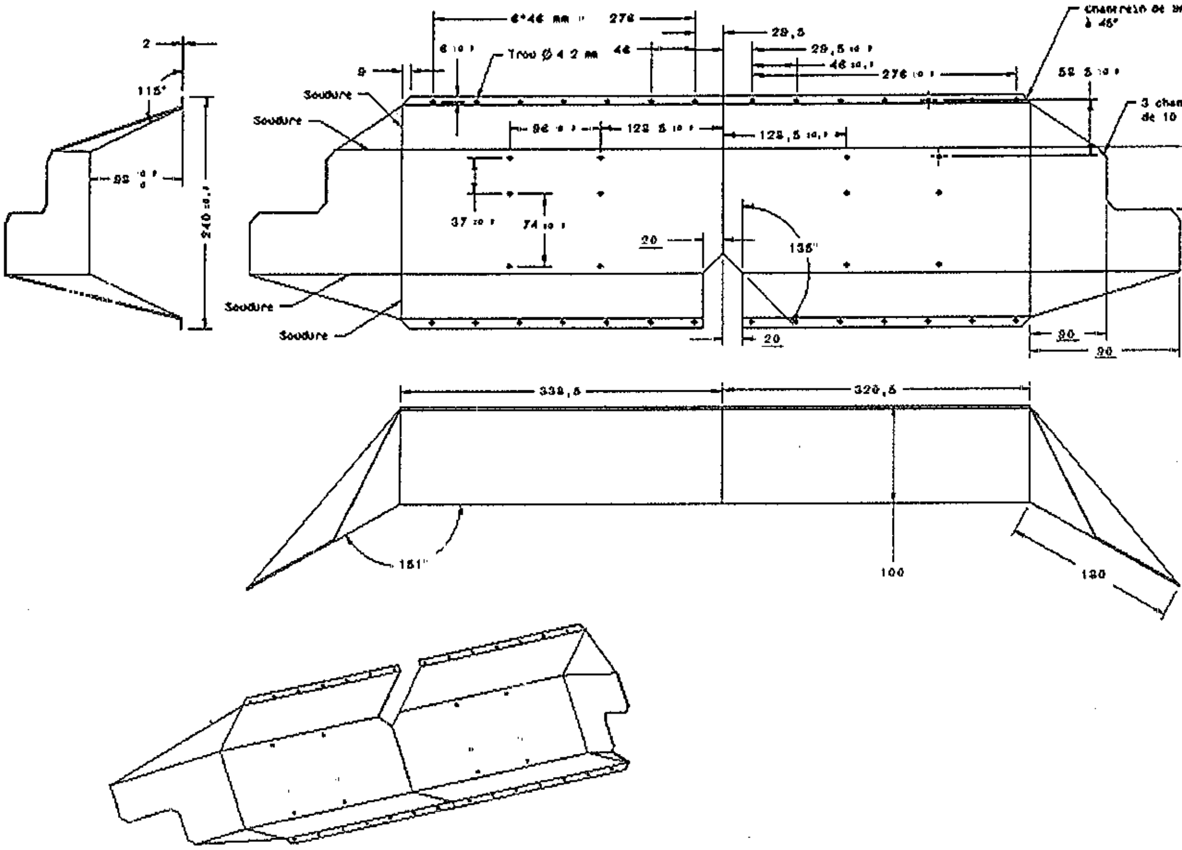


Fig 4-2: ECAL radiator dimensions

	Radiator area [m²]
RAM	0.257
WAKE	0.257
PORT	0.257
STARBOARD	0.257

Tab 4-1 Radiators area

ECAL radiators are covered with Silver Teflon tape The radiator thermal optical properties coefficients are listed in Tab. 6-2

4.2 MLI

MLI blankets are used to radiatively insulate the units from the environment
MLI is positioned on the nadir and zenith ECAL covers, and over the mounting brackets, in between the winglets of two adjacent sides (see Fig. 4-1).

The blanket is 7 layers aluminized Mylar with white Betacloth outer layer, whose thermo-optical properties are reported in Tab. 6-2

The MLI insulation performance (radiative exchange factor) has been modeled by means of an approximate expression:

$$GR = \varepsilon^{*} \cdot A \cdot \sigma$$

where ε^{*}=0.05, s the Stefan-Boltzmann constant and A is the area of the surface covered with MLI.

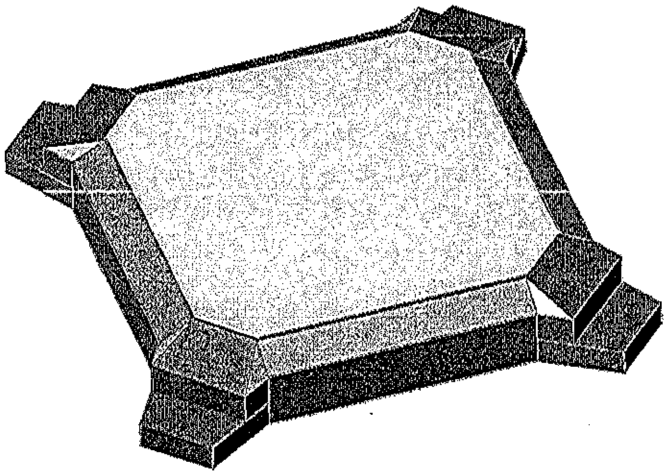


Fig. 4-3: ECAL thermo/optical properties: in magenta and yellow, the MLI covering the brackets (between the winglets) and the one covering the upper and lower honeycomb panels. In blue, the radiators

4.3 CONDUCTIVE INTERFACE

The ECAL is fixed on the Unique Support Structure (USS02), by means of four aluminum brackets visible in Fig. 4-1, at the four corner of the ECAL squared shape.
These conductive links take into account: conductivity through aluminium (155 W/(mK)), the contact between the two pieces by which the brackets are composed (500W/(m^2*K)), the conductance through a layer of teflon (0.001m thickness, 0.2 W/(mK)), and the contact between teflon and USS02 (500W/(m^2*K)).

4.4 HEATERS

4.4.1 POWER AND TEMPERATURE RANGE

According to the results of RD 2, we found that 70W total heaters are needed for the ECAL to allow proper operations during all the mission phases.

The sizing orbital cases are the STS free flying EOL COLD case and the switch ON case, which both require a power of about 70W, providing some temperature margins

The heaters shall be located on the ECAL radiators; 4 heater patches are envisaged on each radiator, for a total of 16 patches

ID	Location	Power [W]
1	Ram radiator, upper inclined panel	4.375x2
2	Ram radiator, lower inclined panel	4.375x2
3	Port radiator, upper inclined panel	4.375x2
4	Port radiator, lower inclined panel	4.375x2
5	Wake radiator, upper inclined panel	4.375x2
6	Wake radiator, lower inclined panel	4.375x2
7	Starboard radiator, upper inclined panel	4.375x2

8	Starboard radiator, lower inclined panel	4.375x2
	TOTAL	70

Tab. 4-2: heaters location and sizing

In the following picture the location of heaters on a radiator are shown; the heaters will be internal to the radiator.

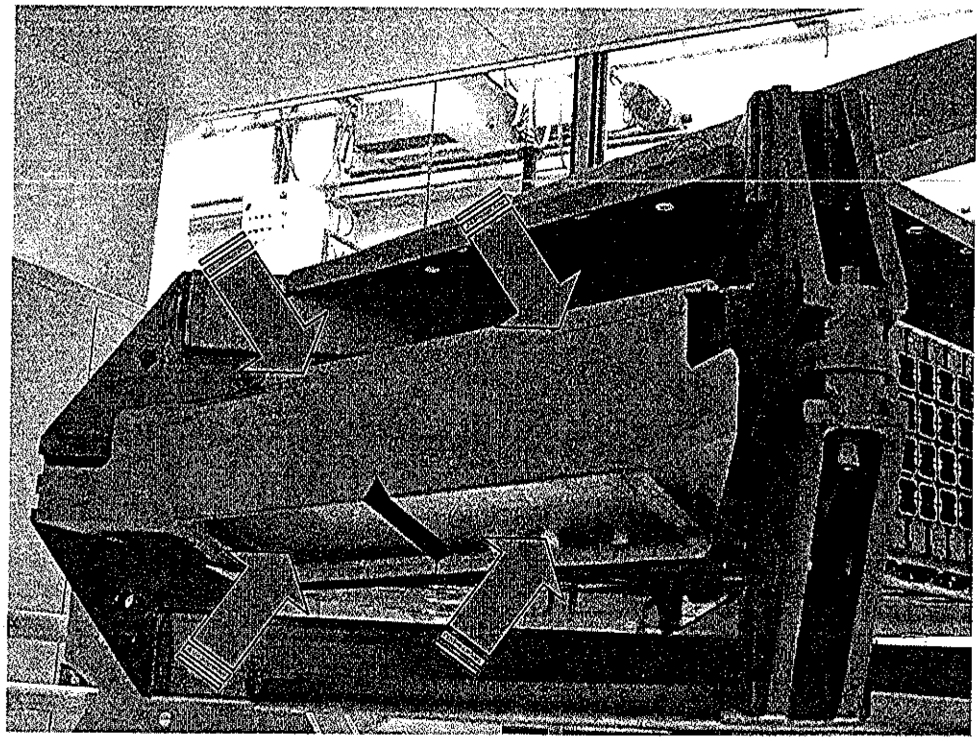


Fig. 4-4: arrows showing the heater patches location on the radiators

Since a single heaters line is available, the choice of thermostat temperature range is made as the most pessimistic in terms of needed power and reference temperature

Therefore, **the minimum heater power required is 70 W, with a thermostat switch on temperature of –18°C and a switch off temperature of –15 °C.**

The –18°C thermostat switch on temperature was chosen to be at least 2°C lower than the minimum operational temperature reached by the ECal in the worst cold cases, in order to avoid as far as possible the heaters switch on when the system is operational If by chance the system experiences temperatures lower than –18°C, the heaters would be ON, and would easily prevent the system from reaching the lower non operational limit of –30°C with a broad margin (both in terms of power and time)

The –15°C thermostat switch off temperature was chosen to have about 3°C temperature range of commercial thermostat

4.4.2 ELECTRICAL AND PHYSICAL LAYOUT

The heater electric circuit schematics is shown below: a main and a redundant line shall be present, each one controlled with a thermostat The heater patches shall be double sided, and the same patch will host the connector of both the main and the redundant circuit

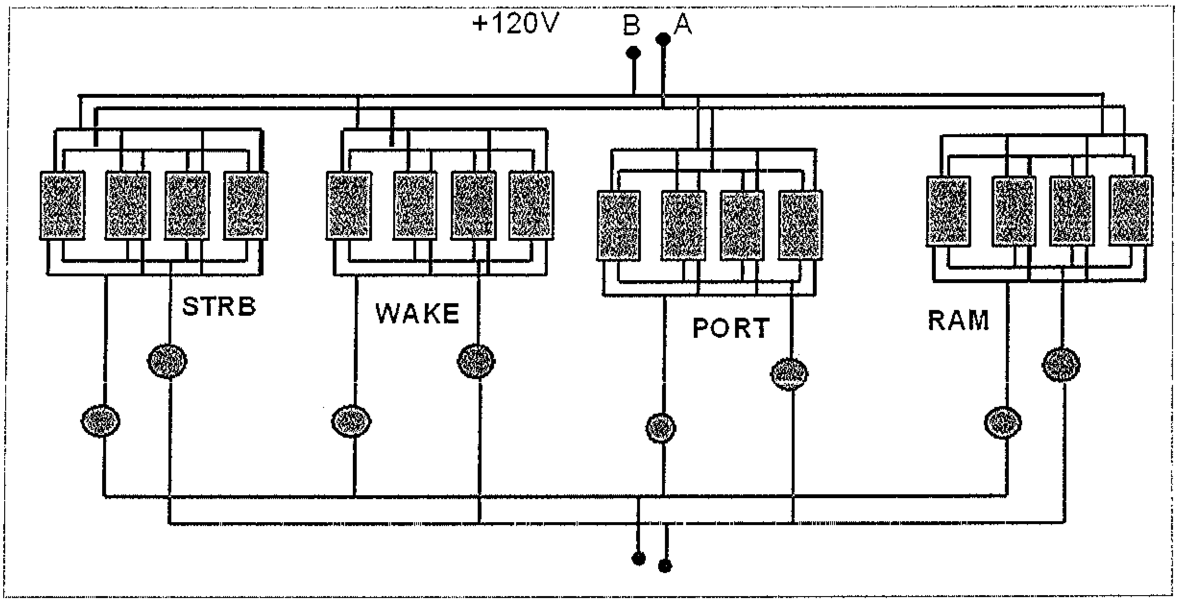


Fig. 4-5: Heaters circuit schematics; main and redundant (A and B) lines are present, and each side of the ECAL shall be controlled with a separate thermostat (redunded)

In the following pictures the location of the thermostat is shown; the back panel close to the mounting brackets is the best choice, being the back panel temperature close to the coldest PMT one. Also a concept of the harness routing is presented

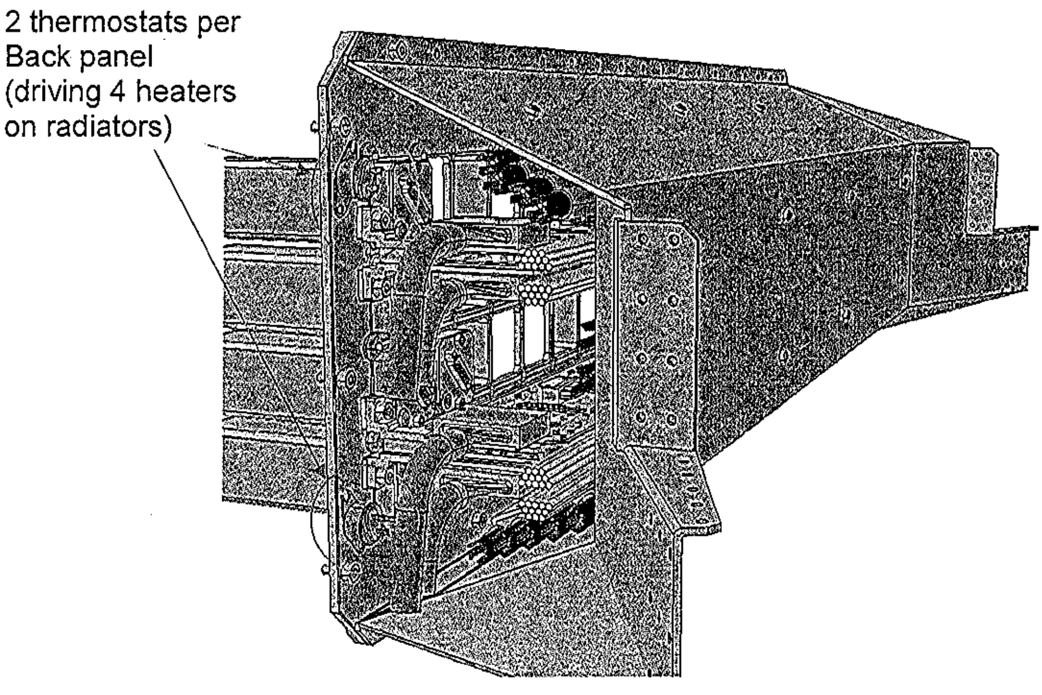


Fig 4-6: location of the thermostat (main and redundant) on the back panel

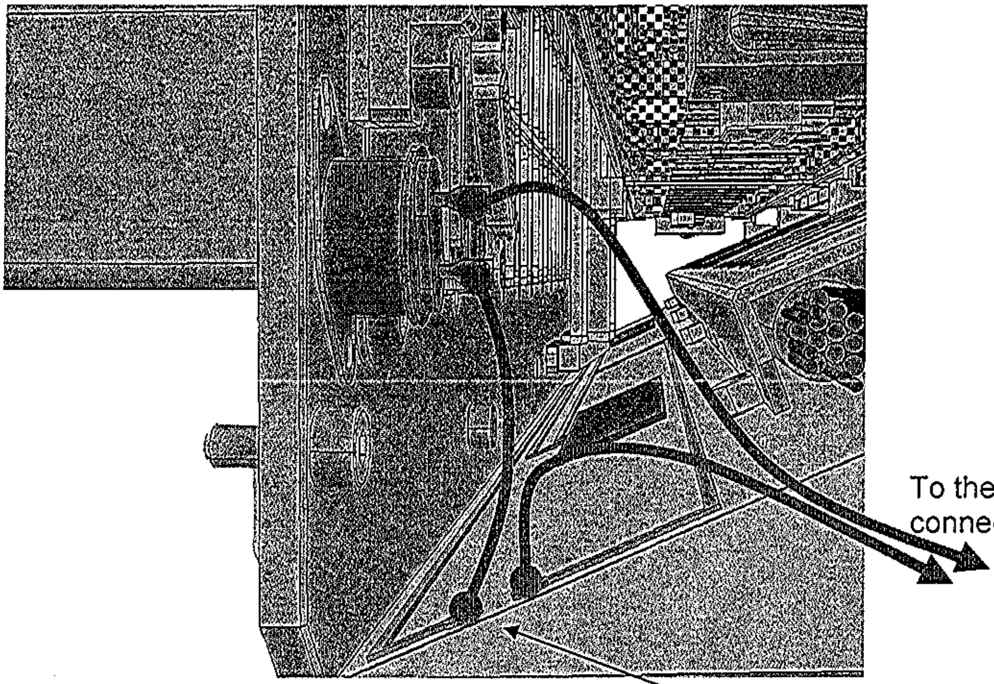


Fig. 4-7: concept of the connection from the thermostat to the radiator heaters circuit.

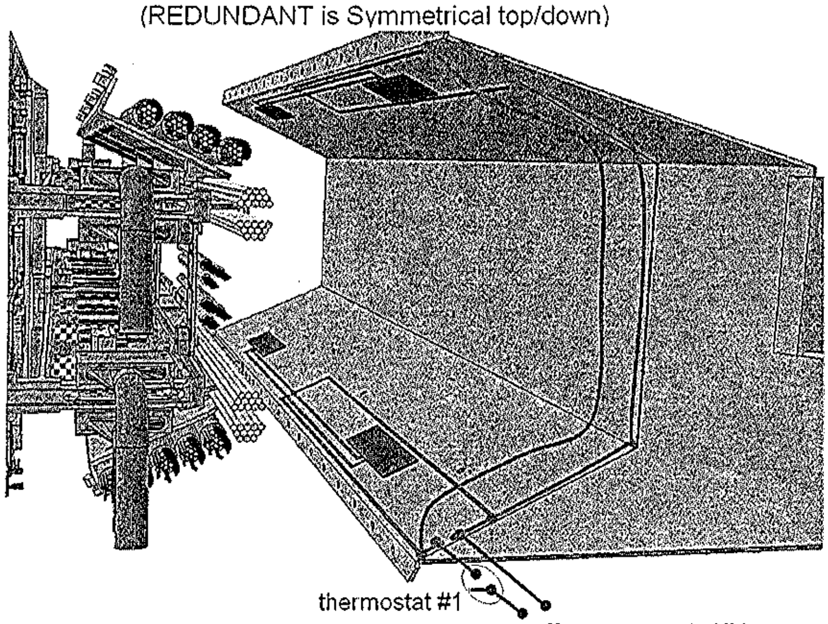


Fig. 4-8: Heaters patches on the radiator, only the MAIN part of the circuit is shown. The redundant circuit is symmetrical top-down, and controlled by the second thermostat.

4.4.3 HARDWARE SPECIFICATIONS

The heaters shall be made of a kapton film, with embedded the main and redundant circuit.

Each patch must provide a heating power of at least 4 375W when fed at the minimum voltage; the minimum voltage is 113V for the 120V nominal lines Therefore the electrical resistance of the heater shall be

$R=V^2/P=113^2/4\,375 = 2\,918$ kΩ.

This means that the power provided by the line at the maximum voltage (126 5V) is

$P_{MAX}=V_{MAX}^2/R= 5\,48W$

Being the maximum allowable power density on the heater equal to 0 27W/cm², the area of the heater must be at least:

$A_{MIN} = 5.48/0\,27 = 20\,4$ cm².

Considering a 2% tolerance in the resistance, a patch with dimension of at least 25 x 100 mm² is required, for a nominal resistance of 2.85 kΩ and a nominal voltage of 120V. These values provide a min/max power of 4.39/5.61W, and a power density lower than 0 22 W/cm².

The **NOMINAL POWER BUDGET** for the ECAL heaters, therefore, calculated at 120V, is:

16 patches x $(120\ V)^2$ / 2850 Ω = 80.8W

5. THERMAL LOADS

5.1 INTERNAL LOADS

Totally 49 6 W are dissipated on 324 PMTs (0 153 W each) when fed at maximum power. The dissipation of the PMT electronics is located spread along three boards according to the following scheme:
EFE: 0.025 W
Board 1: 0 0953 W
Board 2: 0 030 W

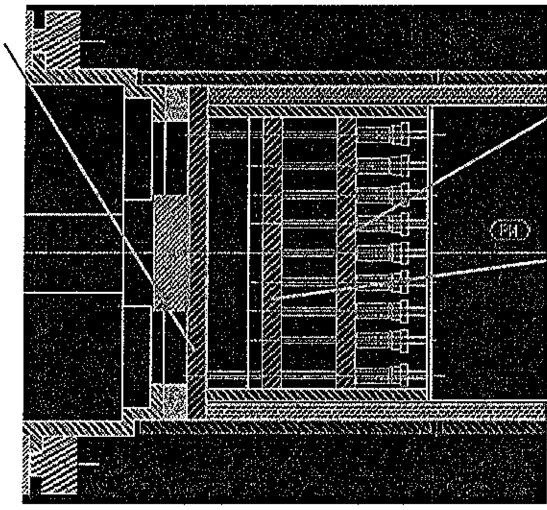


Fig 5-1: Heat source location in the PMT boards and FE board

Additional 17 76 W are dissipated on the 36 EIBs (0 360 W on 12 of them, 0 560 W on the remaining 24 equipped with the trigger electronics).

The total ECAL dissipation is summarized in the following table:

Location	Dissipation [W]
PMTs on RAM and WAKE	(0.153 x 72 = 11.0 each side) x 2 = 22.0
PMTs on PORT and STARBOARD	(0.153 x 90 = 13.8 each side) x 2 = 27.5
EIB ram side	0.560*6+0.360*2=4 08
EIB wake side	0.560*6+0.360*2=4 08
EIB strb side	0.560*6+0.360*4=4.80
EIB port side	0.560*6+0.360*4=4.80
TOTAL	**71.6**

Tab. 5-1 ECAL power budget

In the cold cases analysis, the dissipation on the PMTs has been lowered to 0.107 W each, the other dissipation values remaining the same, so reaching a total power of 52.4W.

5.2 EXTERNAL LOADS

ECAL is located in AMS-02 experiment , which experiences typical external ISS payloads environmental conditions and fluxes in Low Earth Orbit (LEO).

In order to consider the radiative loads impinging over ECAL surfaces due to the presence of sun and earth, the data in Fig. 5-2 have been input in the GMM.

Parameter	Hot cases	Cold Cases
Solar constant	1424 3 W/m^2	1322 W/m^2
Albedo	0 4	0.2
Earth flux	266 5 W/m^2	245.5 W/m^2
ISS orbit height	150 nmi	270 nmi
Thermo-optical database	EOL	BOL

Fig 5-2 Parameters influencing external loads

ECAL location makes it subjected not only to these direct impinging fluxes, but also to reflections of the aforementioned contributions by other ISS elements.

ECAL impinging heating rates, radiative links and sink temperatures have been generated at system level by AMS-02 thermal team.

6. THERMAL MODELLING

6.1 PHYSICAL PROPERTIES

6.1.1 MATERIALS AND MATERIAL PROPERTIES

The following table shows the ECAL materials and the conductivities used in the thermal mathematical model:

Component	Material	Density [Kg/m^3]	Specific Heat [J/Kg/K]	Conductivity [W/m /K]
Radiators	Aluminum	2700	900	155
Pancake	60% Lead 40% plexiglas	11340 1200	129 1297	0.36 perpendicular to the fibers plane 23.2 along the fibers 12.9 in the plane, perpendicular to the fibers
Upper and lower covers	Honeycomb	400	250	0.31W/K/square
Lateral panels	Aluminum	2700	900	155
Back panels	Aluminum	2700	900	155
Brackets	Aluminum	2700	900	155
Endcaps	Aluminum	2700	900	155

Tab 6-1 Summary of used materials

The dependence from temperature of the above mentioned quantities has been neglected

6.1.2 CONTACT CONDUCTANCES

The following values have been used to introduce in the model the thermal joint conductance between different parts:

- **500 W/m^{2}K** : contact conductance between Al alloy - Honeycomb (Al skin)
- **500 W/m^{2}K** : contact conductance between Al - Al surfaces
- **500 W/m^{2}K** : contact conductance between Al - Teflon surfaces
- **900 W/m^{2}K** : contact conductance between Al alloy - Al alloy surfaces
- **1000 W/m^{2}K** : contact conductance between pancake and lateral panels (using thermal filler)

6.2 OPTICAL PROPERTIES

Tab 6-2 contains a summary of the optical properties used in AMS02 model

		BOL (cold analysis)	EOL (hot analysis)
β cloth	α	0.22	0.47
	ε	0.9	0.86
Silver Teflon	α	0.09	0.15
	ε	0.89	0.85

Tab. 6-2 External optical properties

6.3 THERMAL MATHEMATICAL MODEL

The main division in thermal submodels (used in SINDA code) is listed in the following table; a Thermal Mathematical Model has been generated, consisting of **1962** nodes for the representation of the following items:

SUBMODEL NAME	DESCRIPTION	NUMBER OF NODES
PAN	Pancake	81
ULC	Upper and lower covers	36
LATx	Lateral Panels	140 x 2 120 x 2
BACKx	Back panels	133 x 2 114 x 2
FIXX	Brackets	4
PMx	PMTs	72 x 2 90 x 2
ECx	End caps	72 x 2 90 x 2
EIBx	EIBs electronic boards	16 x 2 20 x 2
RAD	Radiators	56
ELEC/USS02	Crates and USS02 thermal sink	5
SINK	Environment nodes	46
Total number of nodes		**1962**

Tab 6-3 Submodel lists and number of nodes

6.3.1 PANCAKE NODAL BREAK-DOWN

The lead Pancake has been included in the model with 9 series of 9 nodes, each series representing the nodal breakdown of each superlayer (composed by optical fibers and lead), as shown in Tab. 6-4. The used material properties are:

- Lead: density 11340 kg/m^3; specific heat 129 J/(kg K);
- Optical fiber and glue: density 1200 kg/m^3; specific heat 1297 J/(kg K)

NODE NUMBER	DESCRIPTION	MAIN CAPACITANCE PARAMETERS
1101,2201,3301,4401,1301,2301, 2401,1401,5501	Pancake, nadir layer	Cpd= 1.5e6 J/(kg*K*m^3)
1102,2202,3302,4402,1302,2302, 2402,1402,5502	Pancake, layer 2	Cpd= 1.5e6 J/(kg*K*m^3)
1103,2203,3303,4403,1303,2303, 2403,1403,5503	Pancake, layer 3	Cpd= 1.5e6 J/(kg*K*m^3)
1104,2204,3304,4404,1304,2304, 2404,1404,5504	Pancake, layer 4	Cpd= 1.5e6 J/(kg*K*m^3)
1105,2205,3305,4405,1305,2305, 2405,1405,5505	Pancake, layer 5	Cpd= 1.5e6 J/(kg*K*m^3)
1106,2206,3306,4406,1306,2306, 2406,1406,5506	Pancake, layer 6	Cpd= 1.5e6 J/(kg*K*m^3)
1107,2207,3307,4407,1307,2307, 2407,1407,5507	Pancake, layer 7	Cpd= 1.5e6 J/(kg*K*m^3)
1108,2208,3308,4408,1308,2308, 2408,1408,5508	Pancake, layer 8	Cpd= 1.5e6 J/(kg*K*m^3)
1109,2209,3309,4409,1309,2309, 2409,1409,5509	Pancake, zenith layer	Cpd= 1.5e6 J/(kg*K*m^3)

Tab. 6-4 Pancake nodes numbering

(*)- cpd: volumic specific heat has been calculated assuming a volumic composition of the pancake layer of 60% lead and 40% plexiglas.

6.3.2 UPPER AND LOWER COVERS NODAL BREAK-DOWN

Upper and lower covers are made of honeycomb (26 mm thick) (core and skin made of Aluminum) and are externally covered by MLI.

The nodes included in the model are listed in the following table, with their properties:

NODE NUMBER	DESCRIPTION	Specific Heat [J/Kg/K]
111,221,331,441,551,131,141,231,241	Honeycomb for nadir side	250
119,229,339,449,559,139,149,239,249	Honeycomb for zenith side	250
5111,5221,5331,5441,5551, 5131,5141,5231,5241, 5119,5229,5339,5449,5559, 5139,5149,5239,5249	MLI nodes	Arith.

Tab. 6-5 Upper and lower covers nodes numbering

6.3.3 LATERAL PANELS NODAL BREAK-DOWN

The lead pancake is fixed to four aluminum panels.
In the thermal model there are 4 different submodels, corresponding to each lateral panel in the following way:

SUBMODEL NAME	POSITION	NUMBER of NODES
LAT1	RAM	140
LAT2	WAKE	140
LAT3	STARBOARD	120
LAT4	PORT	120

Tab 6-6 Lateral Panels Submodels

Panels LAT1 and LAT2 are identical and so the have the same nodal break-down. The same is true for panels LAT3 and LAT4
The differences between them are due to the number of PMT's holes present in each type of panel (ram and wake with 72 PMTs, port e starboard with 90 PMTs each).

The nodes included in the model are listed in the following table, with their properties:

SUBMODEL	NODE NUMBER	DESCRIPTION	Specific Heat [J/Kg/K]
LAT1	1000-1019, 2000-2019, 3000-3019, 4000-4019, 5000-5019, 6000-6019, 7000-7019	RAM Aluminum panel	900
LAT2	1000-1019, 2000-2019, 3000-3019, 4000-4019, 5000-5019, 6000-6019, 7000-7019	WAKE Aluminum panel	900
LAT3	1000-1019, 2000-2019, 3000-3019, 4000-4019, 5000-5019, 6000-6019	STARBOARD Aluminum panel	900
LAT4	1000-1019, 2000-2019, 3000-3019, 4000-4019, 5000-5019, 6000-6019	PORT Aluminum panel	900

Tab 6-7 Lateral panels nodes numbering

6.3.4 BACK PANELS NODAL BREAK-DOWN

The back panels close the PMT assemblies and press them towards the pancake and the lateral panels.
In the thermal model there are 4 different submodels, corresponding to each back panel in the following way:

SUBMODEL NAME	POSITION	NUMBER of NODES
BACK1	RAM	133
BACK2	WAKE	133
BACK3	STARBOARD	114
BACK4	PORT	114

Tab. 6-8 Back Panels Submodels

Panels BACK1 and BACK2 are identical and so the have the same nodal break-down. The same is true for panels BACK3 and BACK4. The differences between them are due to the number of PMT's holes present in each type of panel (ram and wake with 72 PMTs, port e starboard with 90 PMTs each).

The nodal breakdown of the back panels is completely identical to the lateral panels (see Tab. 6-7), with the only difference that the series x018 (x=1..7) are missing for geometrical reasons: the lateral panel nodes labeled like x018 are in a geometrical correspondence with some holes drilled on the back panels for mass saving purposes

6.3.5 BRACKETS NODAL BREAK-DOWN

Four aluminum brackets are used to connect ECAL to USS02

The nodes included in the model are listed in the following table, with their properties:

NODE NUMBER	DESCRIPTION	Specific Heat [J/Kg/K]
13	STARBOARD-RAM Aluminum bracket	900
14	PORT-RAM Aluminum bracket	900
24	PORT-WAKE Aluminum bracket	900
23	STARBOARD-WAKE Aluminum bracket	900

Tab. 6-9 Brackets nodes numbering

6.3.6 PMTS NODAL BREAK-DOWN

Each PMT has been modeled using only one node, representing all the PMT assembly (PM and electronics).
In the thermal model there are 4 different submodels, in order to have a correspondence with the aluminium panels on wich the PMTs are mounted

SUBMODEL NAME	POSITION	NUMBER of NODES
PM1	RAM	72
PM2	WAKE	72
PM3	STARBOARD	90
PM4	PORT	90

Tab 6-10 PMT Submodels

The nodes included in the model are listed in the following table, with their properties:

SUBMODEL	NODE NUMBER	DESCRIPTION	THERMAL CAPACITY [J/K]	DISSIPATION [W]
PM1	201 ÷ 218 401 ÷ 418 601 ÷ 618 801 ÷ 818	RAM PMTs	40 9	0.15 W
PM2	201 ÷ 218 401 ÷ 418 601 ÷ 618 801 ÷ 818	WAKE PMTs	40 9	0 15 W
PM3	101 ÷ 118 301 ÷ 318 501 ÷ 518 701 ÷ 718 901 ÷ 918	PORT PMTs	40 9	0.15 W
PM4	101 ÷ 118 301 ÷ 318 501 ÷ 518 701 ÷ 718 901 ÷ 918	PORT PMTs	40 9	0.15 W

Tab. 6-11 PMTs nodes numbering

6.3.7 END CAPS NODAL BREAK-DOWN

The back part of each PMT has been modeled with one node; this node is the interface for the connection between PMT and back panels.
In the thermal model there are 4 different submodels, corresponding to each back panel in the following way:

SUBMODEL NAME	POSITION	NUMBER of NODES
EC1	RAM	72
EC2	WAKE	72
EC3	STARBOARD	90
EC4	PORT	90

Tab. 6-12 End Caps Submodels

The nodes included in the model are listed in the following table, with their properties:

SUBMODEL	NODE NUMBER	DESCRIPTION	THERMAL CAPACITY [J/K]
EC1	201 ÷ 218	RAM End Caps	14.4

SUBMODEL	NODE NUMBER	DESCRIPTION	THERMAL CAPACITY [J/K]
	401 ÷ 418 601 ÷ 618 801 ÷ 818		
EC2	201 ÷ 218 401 ÷ 418 601 ÷ 618 801 ÷ 818	WAKE End Caps	14.4
EC3	101 ÷ 118 301 ÷ 318 501 ÷ 518 701 ÷ 718 901 ÷ 918	PORT End Caps	14.4
EC4	101 ÷ 118 301 ÷ 318 501 ÷ 518 701 ÷ 718 901 ÷ 918	PORT End Caps	14.4

Tab 6-13 Endcaps nodes numbering

6.3.8 EIBS NODAL BREAK-DOWN

Each EIB is an electronic board that collects signal from 9 different PMTs located in the same row.
In the thermal model there are 4 different submodels, corresponding to each ECAL side in the following way:

SUBMODEL NAME	POSITION	NUMBER of NODES
EIB1	RAM	16
EIB2	WAKE	16
EIB3	STARBOARD	20
EIB4	PORT	20

Tab. 6-14 EIBs Submodels

Each electronic boards is fixed directly to an aluminum frame, which has not dedicated nodes in the model

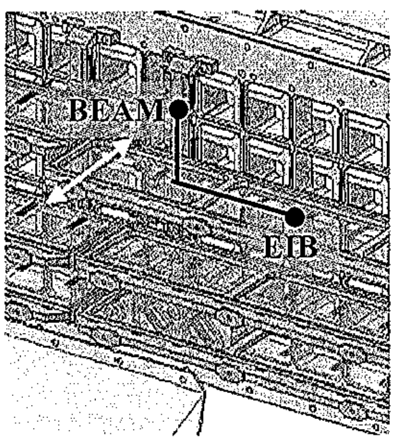


Fig. 6-1: Connection between EIB and its beam

The nodes included in the model are listed in the following table, with their properties:

SUBMODEL	NODE NUMBER	DESCRIPTION	THERMAL CAPACITY [J/K]
EIB1	2011,2012 4011,4012 6011,6012 8011,8012	EIBs on RAM side	228.6
	2111,2112 4111,4112 6111,6112 8111,8112	Fixing beams on RAM	51.3
EIB2	2011,2012 4011,4012 6011,6012 8011,8012	EIBs on WAKE side	228.6
	2111,2112 4111,4112 6111,6112 8111,8112	Fixing beams on WAKE	51.3
EIB3	1011,1012 3011,3012 5011,5012 7011,7012 9011,9012;	EIBs on STARBOARD side	228.6
	1111,1112 3111,3112 5111,5112 7111,7112 9111,9112;	Fixing beams on STARBOARD	51.3
EIB4	1011,1012 3011,3012 5011,5012 7011,7012 9011,9012;	EIBs on PORT side	228.6
	1111,1112 3111,3112 5111,5112 7111,7112 9111,9112;	Fixing beams on PORT	51.3

Tab 6-15: EIBs nodes numbering

The following table shows the EIBs dissipation:

SUBMODEL	NODES	DISSIPATION
EIB1 EIB2	2011,2012 4011,4012 6011,6012	0.56W
	8011,8012	0.36W
EIB3 EIB4	3011,3012 5011,5012 7011,7012	0.56W
	1011,1012 9011,9012	0.36W

Tab 6-16 EIBs dissipation

6.3.9 RADIATORS

Each ECAL side has a 'C-shaped' aluminum radiator, divided in 2 parts Each part has a 'front panel', parallel to ECAL side walls, two inclined panels and 2 lateral winglets.

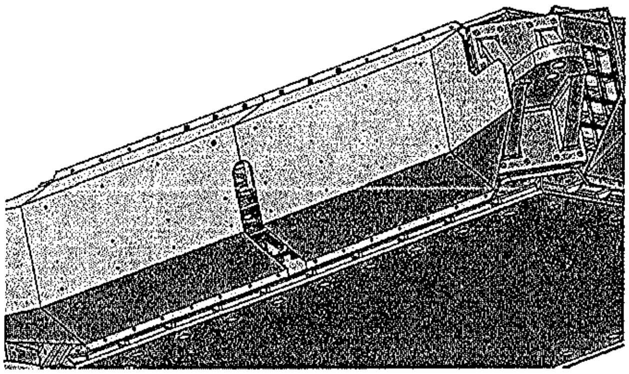


Fig 6-2: 'C-shaped' radiator

The nodes included in the model are listed in the following table, with their properties:

NODE NUMBER	DESCRIPTION		MAIN CAPACITANCE PARAMETERS
30304	half front panel	Wake/port side	Cp=900 J/(kg*K)
30306		Wake/starboard side	
30403		Port/wake side	
30405		Port/ram side	
30504		Ram/port side	
30506		Ram/starboard side	
30603		Starboard/wake side	
30605		Starboard/ram side	
30314,30324	inclined panel	Wake/port side	Cp=900 J/(kg*K)
30316,30326		Wake/starboard side	
30413,30423		Port/wake side	
30415,30425		Port/ram side	
30514,30524		Ram/port side	
30516,30526		Ram/starboard side	
30613,30623		Starboard/wake side	
30615,30625		Starboard/ram side	
301,302	winglet	Wake/port side	Cp=900 J/(kg*K)
311,312		Wake/starboard side	
401,402		Port/wake side	
411,412		Port/ram side	
501,502		Ram/port side	
511,512		Ram/starboard side	
601,602		Starboard/wake side	
611,612		Starboard/ram side	
30301,30302,30311,30312, 30401,30402,30411,30412, 30501,30502,30511,30512, 30601,30602,30611,30612	MLI covering the back of winglets		Arith

Tab. 6-17 Radiators nodes numbering

The geometrical model of the radiators is shown in Fig 6-3

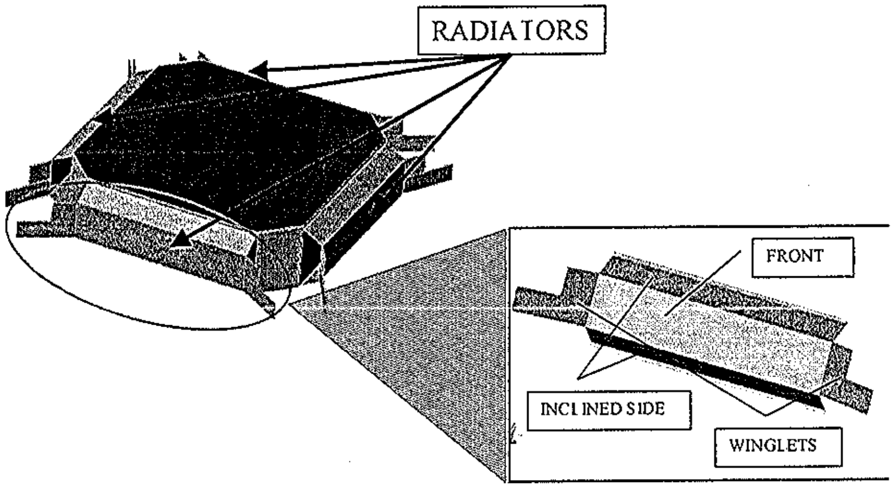


Fig 6-3: Ecal radiators modeled in RadCAD

6.3.10 EXTERNAL ENVIRONMENT

The external environment has been modeled (in the detailed model) by a set of boundary nodes This set was linked either radiatively and conductively to the nodes of the model.

The conductively-linked boundary nodes are represented by the fixation points on the USS02 (4 boundary nodes, one per fixation point), and by the electronic units (1 node). The actual temperature coming from the system level simulation was used in the determination of the temperature of the USS02 boundary nodes. On the contrary, the electronics temperature was set, in a conservative way, to the maximum and minimum operative temperatures of the electronic units (-20°C, +40°C), according to the analysis purpose: cold or hot cases investigation, correspondingly.

The radiative boundaries were provided in the usual format (Sink temperature or MERaT, radiative coupling and external heat loads). These MERaT data were provided for 45 different external surfaces, and eventually splitted when the detailed model node mesh was finer than the reduced model used in the system level simulations.

6.4 GEOMETRIC MATHEMATICAL MODEL

The geometrical mathematical model was used in the Ecal detailed model to find the internal radiative couplings.

The outer surfaces properties were analized in the previous sections, and are included in the system level model: the Radiator surface properties (areas and optical properties) are described in the radiator section, while the optical properties of the MLI which cover the upper and lower honeycomb panels and the brackets are described in Tab. 6-2.

The internal model is represented in Fig 6-4: The brackets are represented by the yellow structures at the corners, the MLI covers in violet, and the radiators in light blue. A radiator has been removed to show the END CAPS arrays behind them (in green, with arrows indicating the active radiating surface).

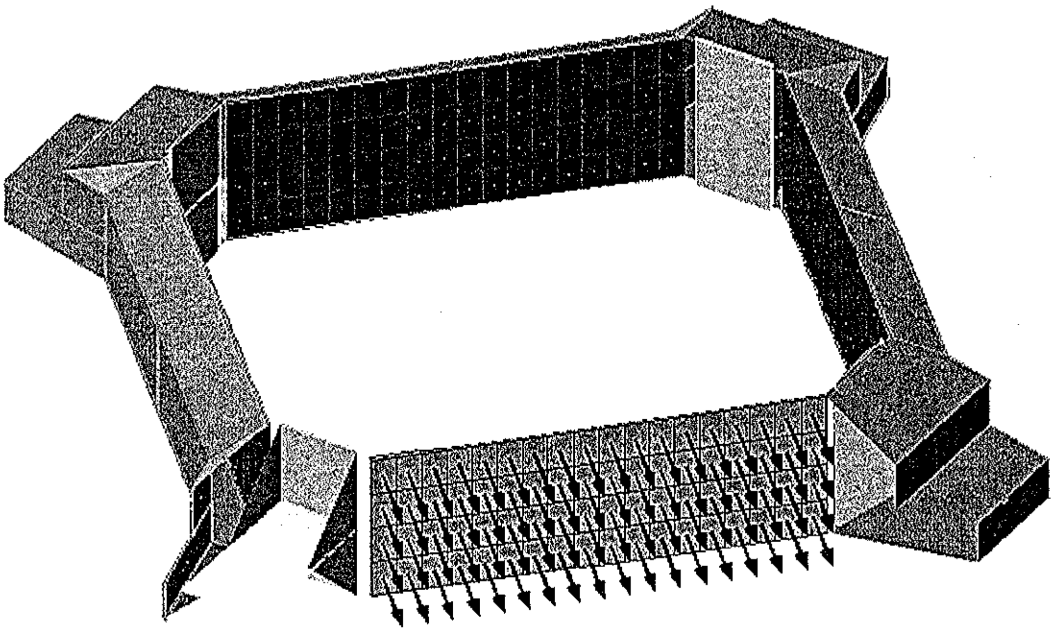


Fig. 6-4: Ecal detailed geometrical mathematical model: the submodels represented are the MLI (violet), the radiators (light blue), the fixation brackets (yellow) and the End Caps (in green) A radiator has been removed. The pancake is missing, since it does not participate to the radiative heat exchange.

The optical properties used in the radiative model are listed in Tab. 6-18; only the e is given, since it is the only relevant property in absence of direct solar radiation

Location	Material	ε
Radiator back side	Clear Anodized	0.84
Brackets	Clear Anodized	0.84
MLI inner face	Aluminized Polymmide	0.05
End Caps	Clear Anodized	0.84

Tab. 6-18: Optical properties used for the various items in the ECAL detailed geometrical model.

7. TEST CORRELATION MODEL DESCRIPTION

The ECAL has been subjected to a Thermal-Vacuum Cycling, to investigate the thermal behaviour of the detector. As per RD3, the unit under test was the Flight Model TCS mounted on the QM detector

The thermal model correlation was included in the test objectives

The starting version of the thermal model which has been used for the model correlation is:
RICSYS-SB-CGS-006 issue 1. (RD 5)

Prior to any model correlation activity, however, the abovementioned ECAL ***flight*** model, as described in the previous sections and in RD 2, had to be aligned to the ***test*** configuration.

From the modelling point of view, the following modifications were applied to the Flight TMM and GMM in order to align it to the test configuration:

1. Most of the PMT and all the EIB in the test were substituted with resistors representing their power dissipation. PMT dummy resistors number was reduced with respect to the total number of flight PMT. In the model, these power sources have been lumped accordingly. The EIB power dummies have been applied in the model according to the test configuration. This configuration is equal in terms of total power dissipated per each ECAL side, but the power sources are grouped in a slightly different way, which has been reproduced in the test correlation model.

2. Dummy PMT and dummy EIB are fed to a unique electrical power supply In the FM, instead, large bundles of cables are present. The contribution to heat conduction of the FM cable bundles has been therefore deleted from the test correlation model.

3. The mechanical frame of EIB are simulated with a L-beam mechanical structure in the test. The dummy EIB are linked only with the radiators, while in the FM the mechanical frame is in contact both with he radiator and with the back panels. In test model the EIB mechanical frame nodes have been removed and also all conductors from back panel to EIB.

4. MLI has been added on upper side of the test model, and it was removed on the 4 mounting brackets at the ECAL corners. In the FM configuration in fact MLI is present on the upper side, but It belongs to the RICH detector; the MLI in between belongs to the RICH sub model.

5. Link between mounting brackets and USS was replaced with values representing the larger thickness of TEFLON used in the test.

8. CORRELATION CRITERIA

In order to achieve a successful correlation 2 criteria must be fulfilled

8.1 AVERAGE CRITERION

The sum of all temperature differences divided by the number of analysed points shall be less than 2 K in modulus.

$$\Delta T = \left| \frac{1}{N} \sum_{i=1}^{N} \left(T_{Mi} - T_{Pi} \right) \right| \leq 2K$$

Where

- ΔT = global temperature deviation
- N = number of temperature points considered for correlation
- T_{Mi} = measured temperature
- T_{Pi} = calculated SINDA temperature

8.2 STANDARD DEVIATION CRITERION

The standard deviation of all temperature differences (measured value minus analytical value) shall be less than 3 K.

$$\sigma = \frac{1}{N-1} \sqrt{\sum_{i=1}^{N} \left[\left(T_{Mi} - T_{Pi} \right) - \Delta T \right]^2} \leq 3\mathrm{K}$$

Where σ is the standard deviation

9. CORRELATION DATA

9.1 TEMPERATURE SENSORS DATA

During the test, temperatures have been acquired for the ECAL, in 64 different locations Each temperature sensor was acquired every 64 seconds. Due to an acquisition error, two channel read the same temperature: channel 31 overwrote channel 30. Therefore, this sensor has to be considered lost and an NCR has been raised (RD4)

The test was consisted of 4 cycles in vacuum; the last cycles was extended in duration in order to attain a stabilization for thermal balance purposes. Data for correlation are relative to the last hour of the thermal balance hot and cold plateaus.

The thermal balance phase is the part of test where ECAL reaches the equilibrium temperatures
It was characterized (in the HOT case) by following requisites:

1 the temperature of the hottest TRP had to reach 40 °C and it had to stay in a range between of 40 °C and 43 °C during all the stabilization duration.
2. every sensor had to show a gradient of temperature less than of 0 5 °C/h during thermal balance phase
3. every sensor had to stay in a windows 1 °C wide.
4 The above mentioned conditions had to be maintained for at least 5 hours

The criteria are similar for the COLD balance case, with the target temperature of the TRP in the range -20÷-23°C.

The following figures represent the temperature of all the 63 sensors in the last hour of the thermal balance in the hot and cold phases. The temperature data for the correlation were obtained averaging these temperatures

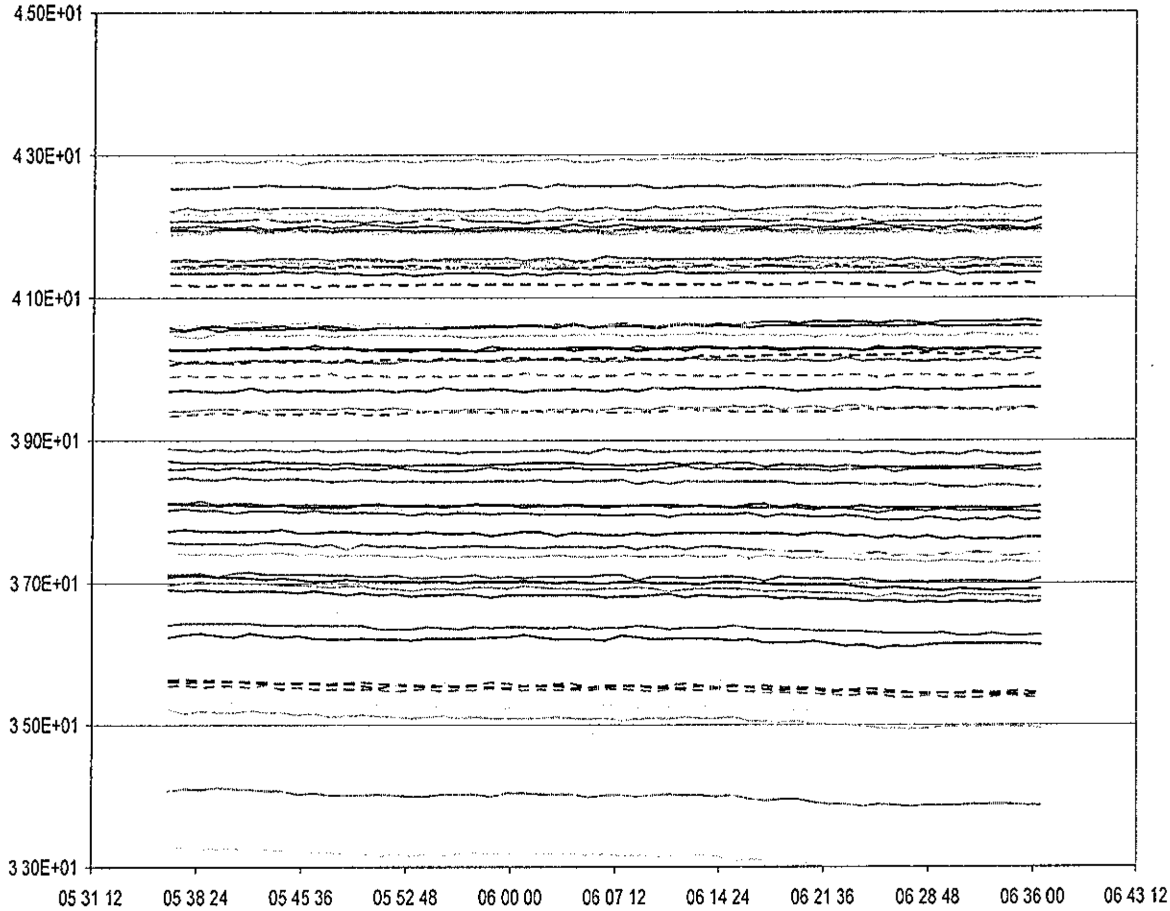


Fig 9-1: temperature (°C) of last hour of thermal balance of 64 sensors: **Hot case correlation data**

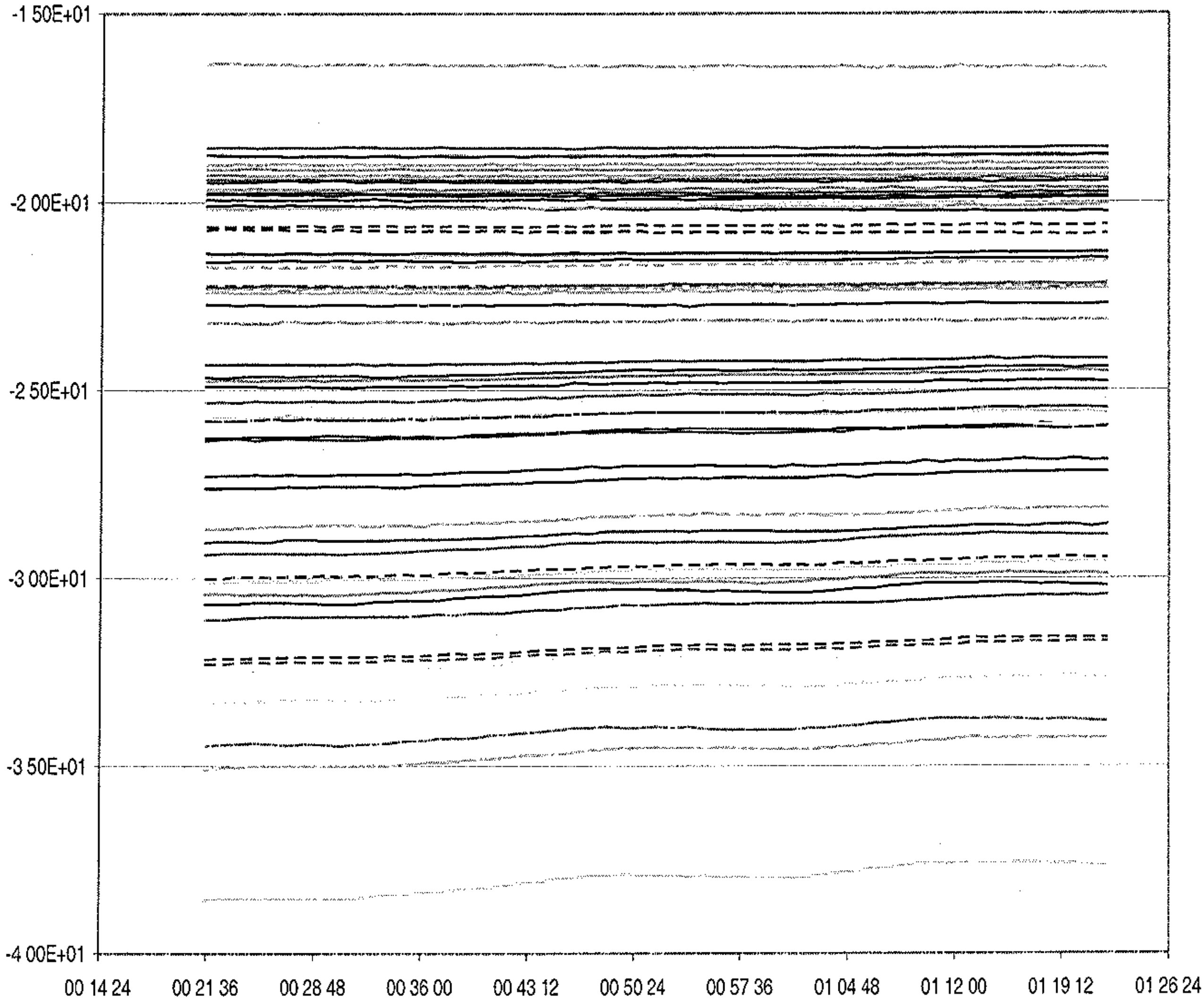


Fig. 9-2: Temperature (°C) of last hour of thermal balance of 64 sensors Cold case correlation data

In the following tables one can find the correspondence between each temperature sensor acquired during the test and the nodes in the TMM (submodel and node ID).

CHANNEL	DESCRIPTION	NODE ID	SUBMODEL
1	Port panel, on End Cap, row 1 column 1	101	EC4
2	Port panel, on End Cap, row 3 column 3	503	EC4
3	Port panel, on End Cap, row 5 column 1 (TRP)	901	EC4
4	Port panel, on End Cap, row 1 column 18	118	EC4
5	Port panel, on End Cap, row 3 column 16	516	EC4
6	Port panel, on End Cap, row 5 column 18 (TRP)	918	EC4
7	Port panel, on End Cap, row 3 column11	511	EC4
8	Lower honeycomb panel, center	551	ULC
9	Lower honeycomb panel, port-wake corner	241	ULC
10	On center of mounting bracket, port-ram-corner	14	FIXX
11	On tip of mounting bracket, starboard-ram corner (center???)	13	FIXX
12	Wake panel, on End Cap, row 3 column 5	605	EC2
13	On tip of mounting bracket, starboard-wake corner	23	FIXX
14	Ram panel, on End Cap, row 2 column 10	410	EC1
15	Ram panel, on End Cap, row 3 column 5	605	EC1
16	Ram radiator, on right central part	30504	RAD
17	Port panel, on End Cap, row 3 column 8 (TRP)	508	EC4
18	Port panel, on End Cap, row 5 column 8	908	EC4
19	Port panel, on End cap, row 3 column 9 (TRP)	509	EC4
20	Port panel, on End Cap, row 5 column 8 redundant	908	EC4
21	Port panel, on End cap , row 3 column 8 redundant	508	EC4
22	Port panel, on Back panel, below row 3 column 8	3008-3009	BACK4
23	Starboard radiator, on right central part	30603	RAD
24	Starboard radiator, on left central part	30605	RAD
25	Wake back panel, behind radiator mounting flange, upper side, at center	7009-7010	BACK2
26	Port radiator, on center of radiator at wake	30403	RAD
27	Port radiator, on center of radiator at ram	30405	RAD
28	Port radiator, on lower inclined radiator at wake	30413	RAD
29	Port radiator, on lower inclined radiator at ram	30415	RAD
~~30~~	~~Port radiator, on upper inclined radiator at wake~~	~~30423~~	~~RAD~~
31	Port radiator, on upper inclined radiator at ram	30425	RAD
32	Port panel, on Back panel, below row 1 column 9	1008-1009	BACK4
33	Port panel, on End Cap, row 1 column 8	108	EC4
34	Port panel, on End Cap, row 1 column 9	109	EC4
35	Port panel, on End Cap, row 1 column 9 redundant	109	EC4
36	Port back panel, behind radiator mounting flange, upper side, at ram	6000-6001	BACK4
37	Port back panel, behind radiator mounting flange, upper side, at center	6009-6010	BACK4
38	Port back panel, behind radiator mounting flange, upper side, at wake	6018-6019	BACK4
39	Port back panel, behind radiator mounting flange, lower side, at center	1009-1010	BACK4
40	Port back panel, behind radiator mounting flange, lower side, at wake	1018-1019	BACK4
41	Wake back panel, behind radiator mounting flange, lower side, at center	1008-1009	BACK2
42	On tip of mounting bracket, port-ram corner	14	FIXX
43	On port back panel, at extreme left (ram), close to mounting bracket	3001-4001	BACK4
44	Port back panel, behind radiator mounting flange, lower side, at ram	1001-1002	BACK4
45	Ram back panel, behind radiator mounting flange, lower side, at center	1009-1010	BACK1
46	Ram back panel, behind radiator mounting flange, upper side, at center	7009-7010	BACK1
47	Starboard back panel, behind radiator mounting flange, lower side, at center	1009-1010	BACK3
48	Ram radiator, on left central part	30506	RAD
49	On port back panel, at extreme right (wake), close to mounting bracket	3019-4019	BACK4
50	On tip of mounting bracket, port-wake corner	24	FIXX
51	On center of mounting bracket, port-wake-corner	24	FIXX
52	Port panel, on PMT body, row 5 column 8	908	PMT4
53	Port panel, on PMT body, row 3 column 9	509	PMT4

CHANNEL	DESCRIPTION	NODE ID	SUBMODEL
54	Port panel, on End Cap, row 3 column 9 redundant	509	EC4
55	Port radiator, on ram winglet	411-412	RAD
56	Port radiator, on wake winglet	401-402	RAD
57	Upper honeycomb panel, port-ram corner	149	ULC
58	Starboard panel, on End Cap, row 3 column 5	505	EC3
59	Starboard panel, on End Cap, row 3 column 14	514	EC3
60	Wake panel, on End Cap, row 1 column 15	215	EC2
61	Upper honeycomb panel, center	559	ULC
62	Wake radiator, on right central part	30306	RAD
63	Wake radiator, on left central part	30304	RAD
64	Ram back panel, at extreme right (starboard side), close to bracket	4001	BACK1

Tab. 9-1: correspondence between test temperature acquisition channels and nodes ID in the thermal model

In the following table we present the average temperature of each sensor in the last hour of thermal balance phase (hot and cold). These data shall be used for the correlation in steady state of the thermal model.

CHANNELS	TMM NODE ID	SUBMODEL	TEST HOT CASE AVERAGE TEMP. °C	TEST COLD CASE AVERAGE TEMP. °C
1	101	EC4	40.3	-21.5
2	503	EC4	41.5	-19.8
3	901	EC4	40.5	-20.8
4	118	EC4	40.5	-21.4
5	516	EC4	41.9	-19.4
6	918	EC4	40.3	-21.3
7	511	EC4	42.6	-18.6
8	551	ULC	40.6	-20.2
9	241	ULC	39.4	-23.2
10	14	FIXX	38.8	-24.3
11	13	FIXX	38.2	-25.3
12	605	EC2	42.1	-20.0
13	23	FIXX	38.0	-25.6
14	410	EC1	42.2	-20.1
15	605	EC1	40.6	-22.4
16	30504	RAD	35.6	-32.9
17	508	EC4	42.1	-19.4
18	908	EC4	41.5	-19.8
19	509	EC4	41.9	-19.3
20	908	EC4	41.9	-19.0
21	508	EC4	41.9	-19.1
22	3008-3009	BACK4	42.2	-18.8
23	30603	RAD	37.5	-29.1
24	30605	RAD	36.9	-30.1
25	7009-7010	BACK2	39.7	-22.7
26	30403	RAD	38.4	-25.2
27	30405	RAD	37.0	-27.4
28	30413	RAD	36.8	-27.1
29	30415	RAD	38.0	-25.6
~~30~~	~~30423~~	~~RAD~~	~~38.1~~	~~-26.1~~

CHANNELS	TMM NODE ID	SUBMODEL	TEST HOT CASE AVERAGE TEMP. °C	TEST COLD CASE AVERAGE TEMP. °C
31	30425	RAD	38.1	-26.1
32	1008-1009	BACK4	41.4	-19.9
33	108	EC4	41.4	-19.6
34	109	EC4	41.3	-19.7
35	109	EC4	41.4	-19.6
36	6000-6001	BACK4	36.2	-30.4
37	6009-6010	BACK4	35.1	-32.2
38	6018-6019	BACK4	34.0	-34.1
39	1009-1010	BACK4	37.4	-28.4
40	1018-1019	BACK4	37.7	-26.1
41	1008-1009	BACK2	37.1	-28.8
42	14	FIXX	38.1	-24.8
43	3001-4001	BACK4	40.1	-22.2
44	1001-1002	BACK4	38.7	-24.5
45	1009-1010	BACK1	36.4	-30.8
46	7009-7010	BACK1	33.1	-38.0
47	1009-1010	BACK3	38.8	-24.6
48	30506	RAD	35.1	-34.6
49	3019-4019	BACK4	38.6	-24.2
50	24	FIXX	36.6	-27.0
51	24	FIXX	37.4	-26.0
52	908	PMT4	40.6	-19.8
53	509	PMT4	42.9	-16.4
54	509	EC4	42.0	-18.8
55	411-412	RAD	35.2	-29.8
56	401-402	RAD	35.5	-29.7
57	149	ULC	39.4	-22.2
58	505	EC3	42.1	-20.0
59	514	EC3	41.5	-21.7
60	215	EC2	41.2	-20.6
61	559	ULC	40.2	-20.8
62	30306	RAD	35.5	-32.0
63	30304	RAD	35.5	-31.9
64	4001	BACK1	39.9	-22.3

Tab. 9-2. Hot and Cold temperature data taken from the test, averaging the last hour of the TB plateaus.

9.2 CHAMBER TEMPERATURE

Chamber temperatures were set by the user, and their values have been acquired by several sensors placed on different location by the facility personnel.
Three main locations have been selected to represent the chamber temperature status
There temperatures are essential for our mathematical model, because we have three boundary nodes, representative of external (boundary) factors. These nodes represent the shroud and the front wall of the TV Chamber, and the structure where the ECAL was mechanically mounted, mimicking the USS-02 of the Flight configuration.

9.2.1 CHAMBER TEMPERATURE HOT CASE:

- shroud average temperature = 30 6 °C
- chamber front wall average temperature = 29.6 °C
- USS02 average temperature = 35.0 °C

9.2.2 CHAMBER TEMPERATURE COLD CASE:

- shroud average temperature = -47.5 °C
- chamber front wall average temperature = -35.8 °C
- USS02 average temperature = -36 0 °C

10. CORRELATION ACTIVITIES

The original thermal model has been run putting as boundary nodes the measured test conditions (external temperatures) and imposing the power dissipation profiles according to the as-run-test.
Results were satisfactory in the hot case, but not in line with the correlation criteria in the cold phase

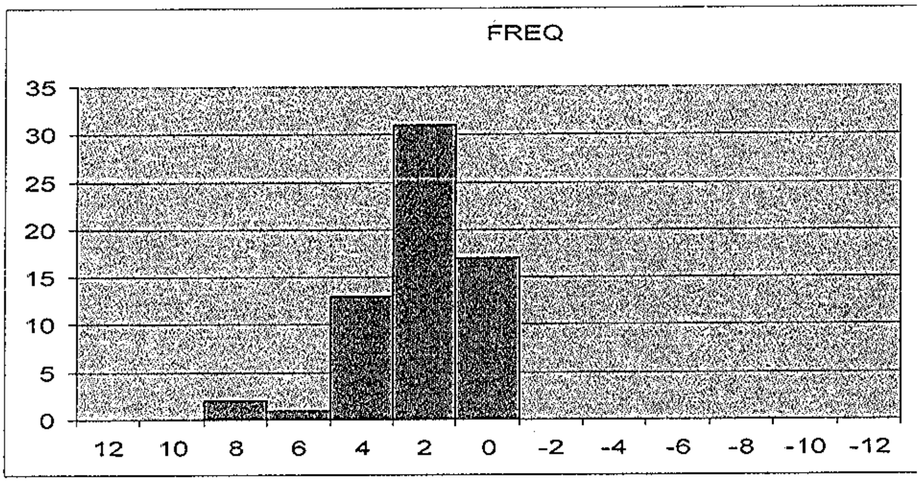


Fig. 10-1: Hot case, temperature differences distribution between mathematical model and test (DT=Model-Test)

Hot case average = - 1.08°C Sigma = 1.69°C

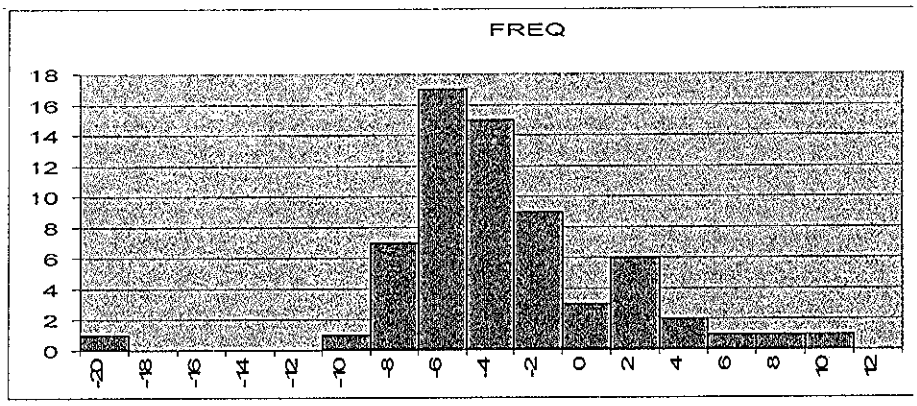


Fig 10-2: Cold case, temperature differences distribution between mathematical model and test (DT=Model-Test)

Cold case average = - 4.48°C Sigma = 4.47°C

10.1 DEFINITION OF COORDINATE SYSTEMS

Before proceeding, it is worth noticing a mismatch between the terminology adopted in the Thermal Analysis Report and in the Test Report (RD 2 and RD 1).
In the TAR the exact AMS and ECAL coordinate systems were shown. Therefore, the 6 directions Ram/wake/port/starboard/Zenith/Nadir are the ones correctly described in RD 2

In the test report, instead, the coordinate system was erroneously rotated by 90° clockwise, therefore the direction which has been indicated by RAM in the test report corresponds in fact to the PORT direction of the thermal model. The correspondence between the test configuration (procedure, report) and the thermal model (model itself and TAR) is given in the figure below.

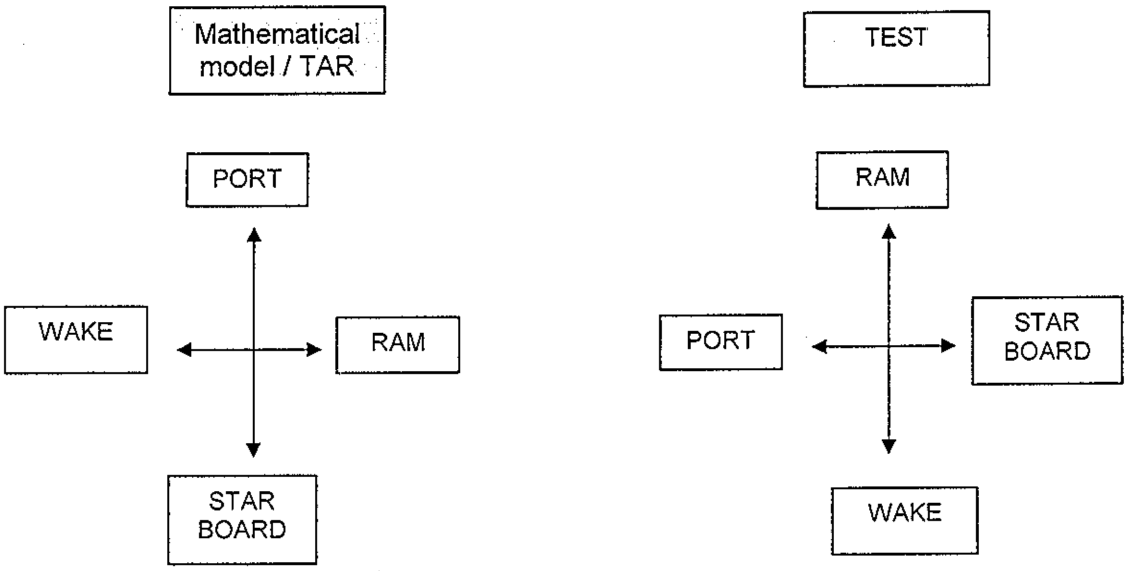


Fig. 10-3: Correspondence between the 2 adopted coordinate systems

Besides the coordinate mismatch, it is worth mentioning that in the test configuration the ECAL was mounted (by test design) with the +Z axis pointing to the ground.
It is important to keep in mind this fact when looking at the ECAL pictures.

10.2 CHAMBER REFINED MODELLING

The test data showed some unbalances among the different sides of the ECAL, which could not be explained by asymmetries in the power loads. Therefore, looking at the chamber walls temperature data, it was realized that some gradients were present at the level of the chamber temperature boundary conditions.

Therefore, it has been necessary to abandon the oversimplified chamber initial model (a sphere with a unique node) and a chamber finer thermal model has been realized in order to account for temperature gradients.

The chamber has been modelled like in the figure below, with different temperatures between the front wall, the coldplates and the rest of the chamber. Fixation points temperatures ("USS02 interface" locations) has been introduced too in the thermal model.

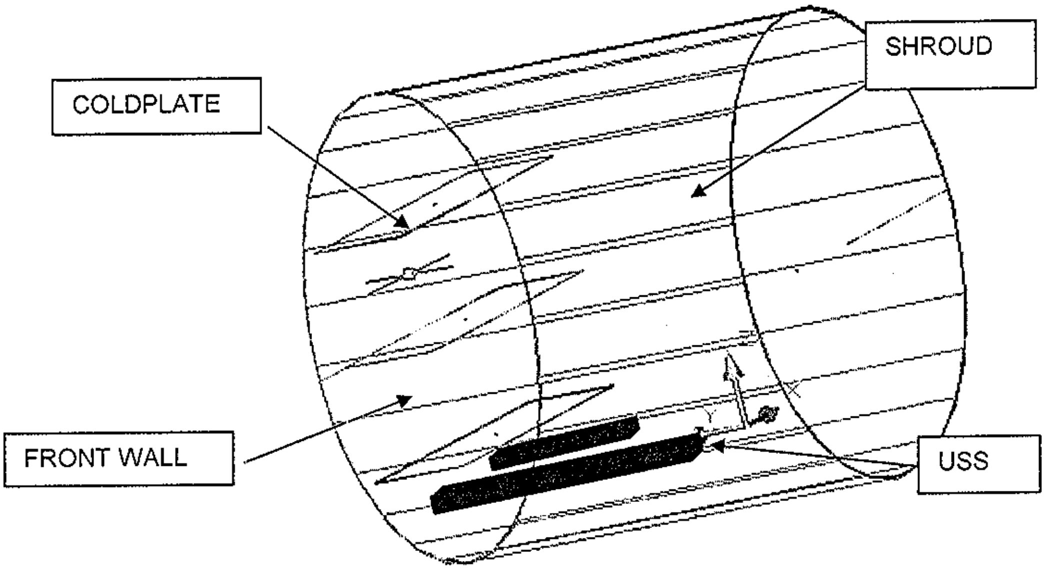


Fig 10-4: Chamber geometrical model. N.B the USS has not been modelled geometrically, and is visualized for clarity only

10.3 ALIGNMENT OF POWER DISSIPATION

The residual temperature unbalances among the ECAL four sides, detected in the test but less marked in the thermal model, have been further reduced (in the model) through a deeper analysis of the power dissipation: despite the total power injected in the model was the same of what measured during the test, particular care was put in the alignment of the exact power dissipated in every chain of dummy heaters

Both EIB and PTM power dummy heaters chains electrical resistances have been measured before and after the test, and the exact power has been applied on the corresponding locations in the thermal model. This lead to the correction of some small temperature unbalances among different sides

10.4 FLANGE GEOMETRICAL MODELLING

As mentioned before, in flight configuration an MLI blanket is present on top of the ECAL (+Z side), in between RICH and ECAL. Being the RICH footprint much larger than the ECAL one, this MLI (which belongs to the RICH detector) covers completely the ECAL top panel
During the test, instead, to allow the mounting of the test MLI on top of the ECAL, few centimeters of back panels were left uncovered (see picture below)

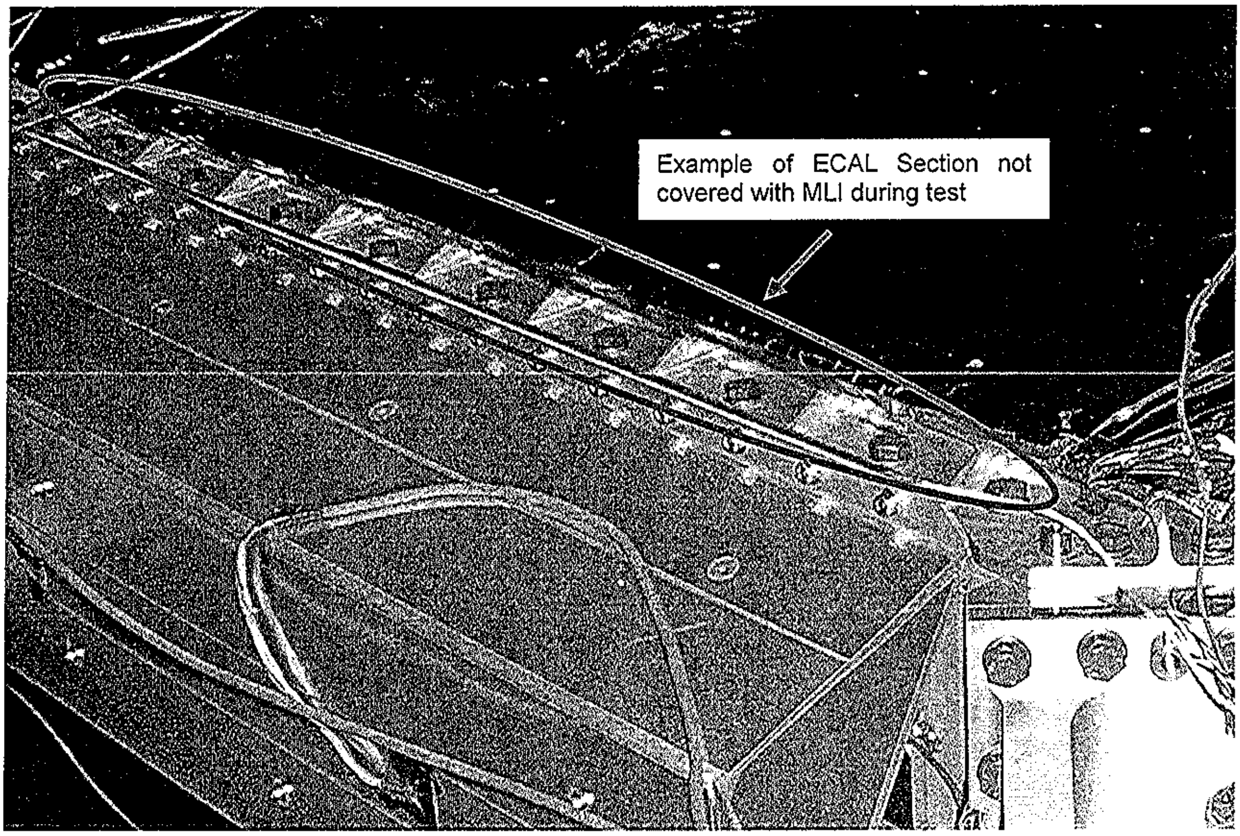


Fig. 10-5. Highlighted in red, an example of an ECAL section not covered with MLI during test

These parts therefore participated to the heat exchange with the cold shroud, but this feature could not be modeled with the actual geometrical model of the ECAL, where the top side was completely covered by the MLI.

A modification of the GMM was needed in order to align the MLI layout. New surfaces associated to the back panels were made radiatively active. Please note that this modification is valid only for the test correlation, but it has to be abandoned when coming back to the flight model.

10.5 ALUMINUM CONDUCTANCE

Radiators aluminum is of type 5051, therefore the used aluminum conductivity has been aligned to the values proper of this type. In particular, Al conductivity was decreased from 155 to 127 W/m/K

10.6 WINGLETS DIFFERENCES AND INTERNAL RADIATORS CONDUCTANCES

The temperature profile of the winglets seemed much colder than predicted. An analysis of the thermal network in fact showed that a non-negligible contribution to the thermal link between winglets and the rest of the radiator was missing

New conductors from winglets to the radiator inclined panels were added, the according to the new network layout depicted below:

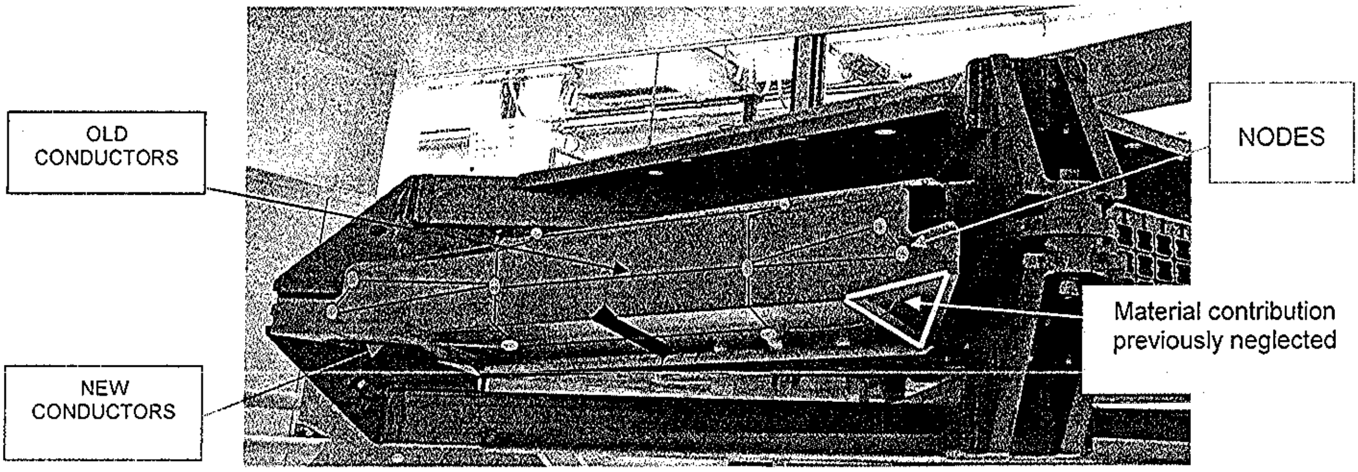


Fig. 10-6: modification in the thermal network of the radiators

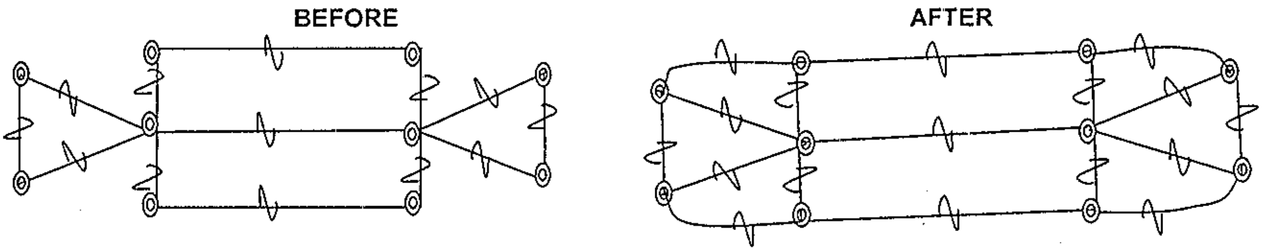


Fig. 10-7. sketch of the thermal network of the radiators before and after the correlation

10.7 PANCAKE BOUNDARY NODES

Looking at the temperature profiles of the sensors close to the pancake (in particular, the upper and lower honeycomb panels), we came to the conclusion that, despite the very strict stabilization requirements and the long dwell time, the PANCAKE didn't reach a perfect equilibrium temperature. This is due to the fact that its lead body is very heavy and it has a very large thermal capacity and a relatively low thermal conductance to the external items.

In order to take into account this fact, the core of the pancake (few nodes at its centre) were converted to boundary nodes This well represents the thermal inertia of the system, whose temperature was not stabilized yet

The choice of the core boundary temperature was made according to the general trend of the temperature profiles, and was estimated to be about 0 6°C lower than its equilibrium temperature in the hot case, and 2 1°C higher than its equilibrium temperature in the cold case.

The inclusion of boundary nodes leads to the equivalent introduction of a heat source/sink in the model. In the hot case, the boundary pancake core drained from the surroundings a total heat flux of ~ 2 W, to be compared to the 66.8 W of total power budget. The introduction of the boundary pancake core affects the energy balance of the ECAL by less than 3 % In the cold case the total power injected by the boundary nodes sums up to 5W, namely 7 5% of the total.

Being the total capacitance of the pancake about 109000 J/K, a constant heat loss of 5W would decrease the pancake average temperature by less than 0 8°C in 5 hours. This calculation serves as a proof that the introduced boundary nodes represent a perfectly reasonable assumption which does not change the power balance of the system

This modification is proper of the correlation with test data, but of course has to be removed from the final flight thermal model.

10.8 FLANGE DETACHED SENSORS

Some sensors applied on difficult-to-reach locations showed a peculiar behaviour In particular these sensors were mounted on the back side of the back panel, in correspondence of the radiator mounting locations.
While some of these sensors showed a temperature in line with the surroundings and in line with the thermal model, other ones had discrepancies up to 13°C (see figure below: sensor #25 w.r.t the four sensors 46, 36, 37 and 38)

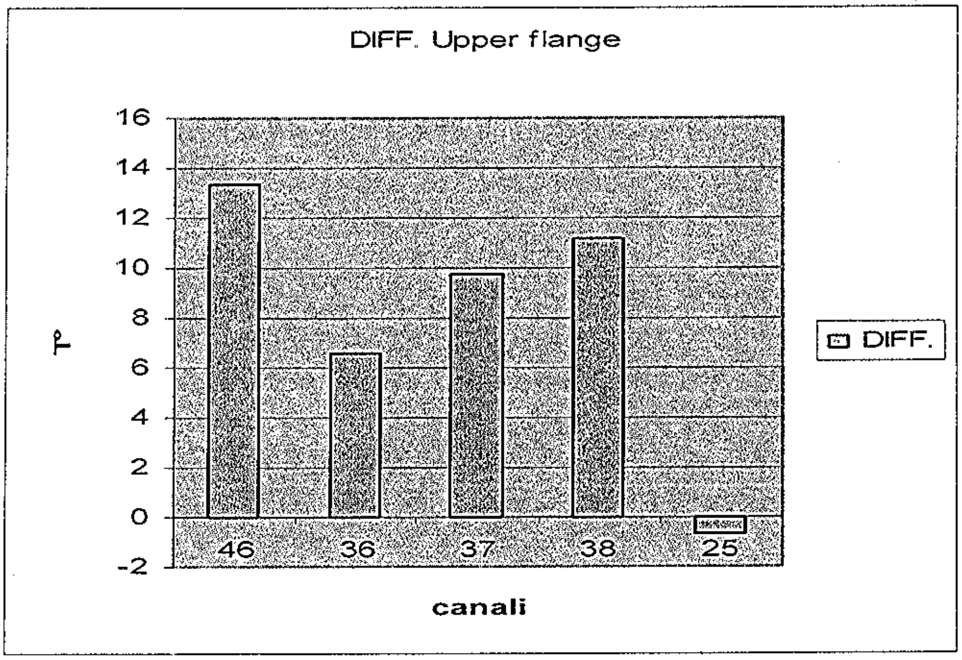


Fig 10-8: temperature differences test/model for 4 suspect locations and a reference good sensor

In particular, for symmetry reasons, sensor #25 temperature should be very similar to sensor number 46 (both located on a back panel, behind radiator mounting flange, upper side, at centre, one at wake and the other at ram). 14°C temperature difference were found instead

Both in hot and in cold cases, the temperature of these sensors was much closer than expected to the camber environmental temperature

Moreover, looking at the transitory response of these sensors, it was possible to observe that sensors like #46 have a much faster temperature change with respect to sensor #25. The sensor #46 temperatures followed the shroud temperature much more closely than sensor #25.

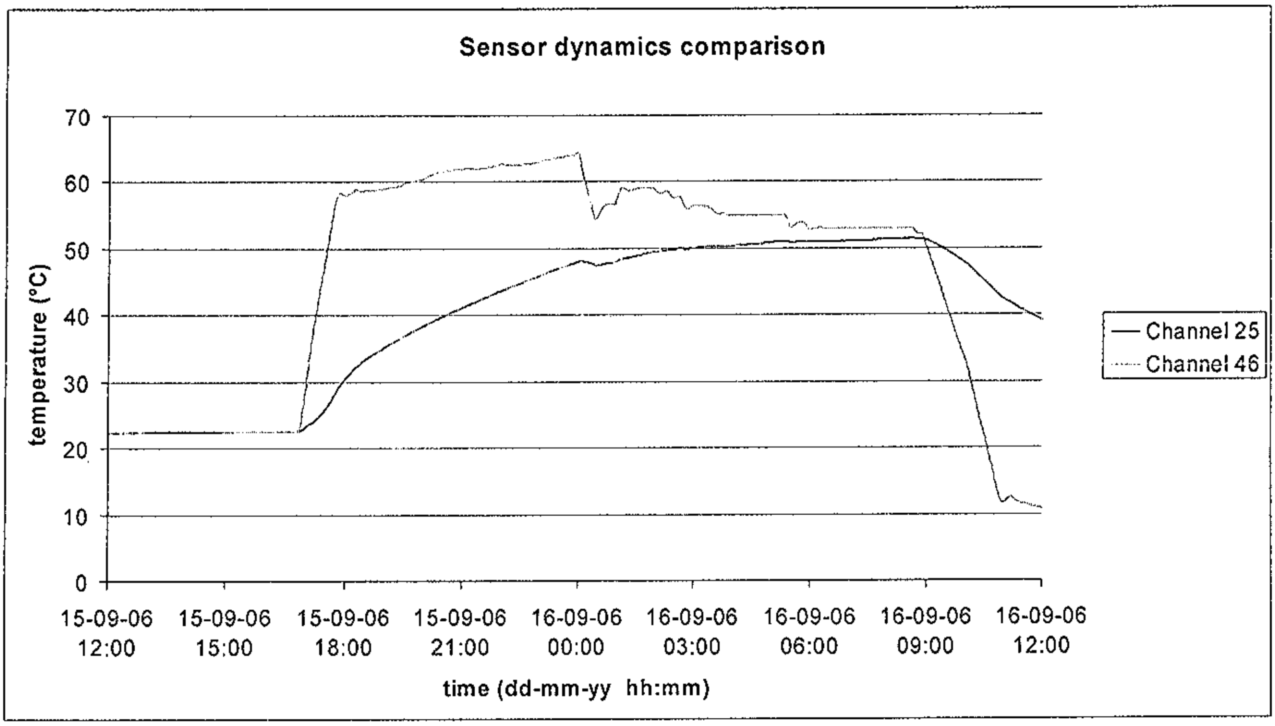


Fig 10-9: different thermal sensors, on equivalent locations

The consideration above lead to the hypothesis that these sensors were poorly coupled to the back panel structure, and their temperature was instead driven by a direct radiative coupling with the chamber (as if the sensor itself was coupled with the fixation tape, in temperature equilibrium only by radiative means, rather than to the mechanical structure)

To simulate the detached sensors, in thermal desktop, we introduced some small rectangles, representing the sensor tape The associated nodes was linked only with radiative couplings to the ECAL and to the chamber.

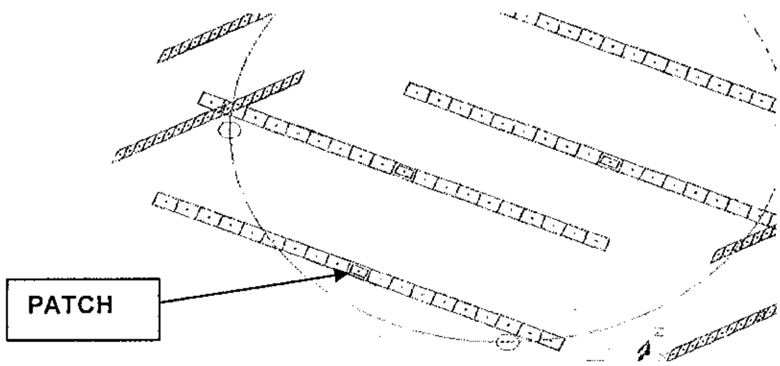


Fig. 10-10: Tape on the detached sensors

Once again, this model modification applies only to the correlation model, but shall be removed from the flight thermal model In fact, this modification serves only to account for some sensors whose temperature does not correspond to any internal temperature of the detector.

Since the additional nodes are not ECAL nodes, but are *ad hoc* inserted nodes, these nodes are excluded from the correlation purposes. In fact, playing with the residual conductive link between the tape patch and the ECAL structure, it would be possible to reduce exactly to zero each individual temperature difference between test and thermal model. This would improve the overall correlation results (lower average difference and lower sigma) without indeed improving the model prediction capabilities

10.9 INTERNAL CONDUCTION

A set of internal linear couplings were slightly modified in order to align the measured temperature profiles with the test data

The rational behind this modification is the following: the complex back panel and lateral panel structure is made of linear links between several nodes. However, the presence of End Caps linking different back panel nodes causes some kind of short-circuit, and enhances the conduction. Moreover, the cross section of the back panel beams is complex, and proper tuning is needed. Connection between the parallel grids of back and lateral panels are mediated with contact conductance whose value has to be refined through comparison with test data. Finally, contact conductance towards the pancake had to be tunes as well

Contact conductances and conductive links were tuned by no more than 30% with respect to their nominal value, according to the list below:

- Every internal conductor of BACK sub model is multiplied by 0.8 to suppress heat transfer and to increase temperature at End Cap level.
- Every internal conductors LAT multiplied by 1.3
- Every conductors from LAT to BACK is multiplied by 1.3
- Conductors from BACK to RAD (contact conductance) are multiplied by 0.7, to align the temperature gap between the two items.
- Conductors from BACK to EC are multiplied by 1.2
- Conductors from BACK to EC are multiplied by 1.2
- Conductors from ULC to LAT are multiplied by 1.3
- Conductors from ULC to PAN are multiplied by 1.2
- Conductors between panels and FIXX (mounting brackets) were multiplied by 0.8 to suppress heat conduction between the back panels and the mechanical mounting locations; between FIXX and ULC the link was kept unchanged
- internal pancake conductors are multiplied by 1.2; between pancake and lateral panels the multiplication factor is 1.3 to attain a lower external insulation. Pancake conductors along Z direction were instead left unchanged

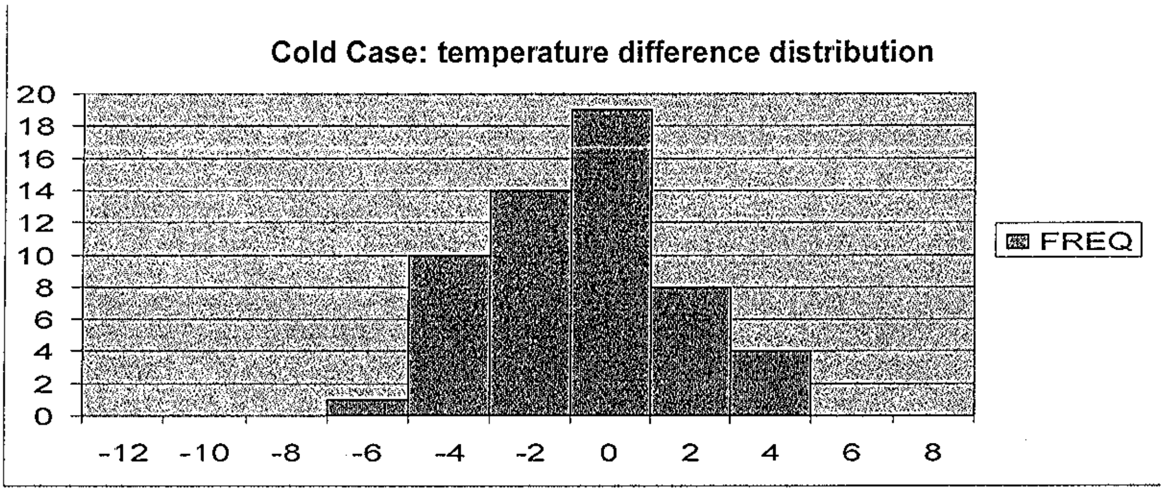
10.10 PMT TO BACK PANEL CONDUCTANCE

The presence of two sensors mounted directly inside the PMT body made it possible to calculate the temperature drop between the PMT body and the Back Panel. Since the power dissipation of the PMT is known, the exact thermal conductance could be inserted in the model, for each PMT

11. CORRELATION FINAL RESULTS

After the correlation activities, the model has been run and the temperature results were compared to the test data. Results are presented in the following sections.

11.1 COLD CASE



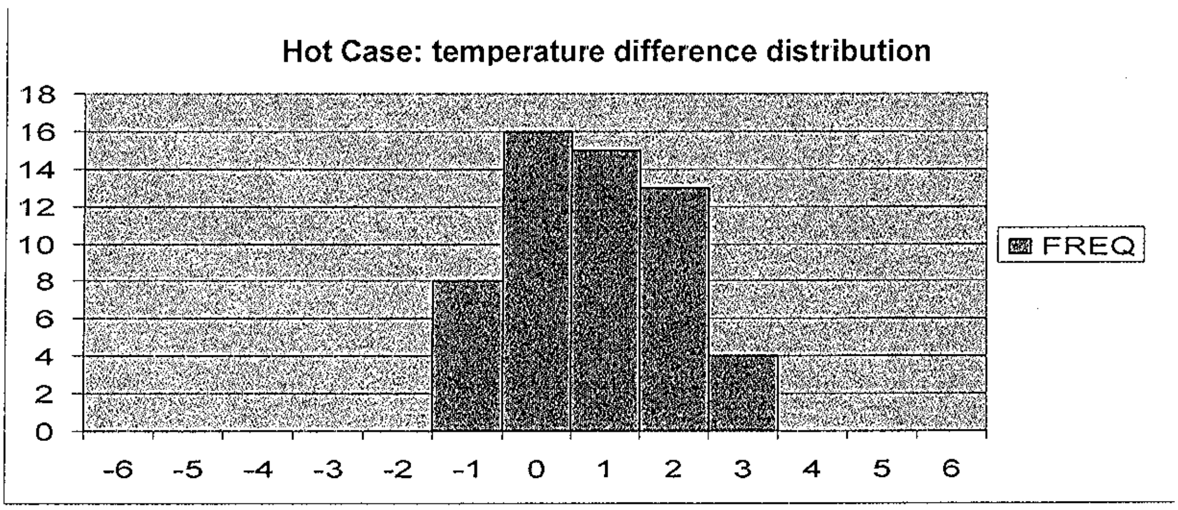
Temperature difference (°C)

Fig. 11-1: test – model correlation final results for the cold case

AVERAGE = -1.68°C **SIGMA = 2.27°C**

The negative average means that the thermal model results are, in average, colder than the test data for the cold balance. This gives an additional conservatism to the thermal model predictions in cold cases.

11.2 HOT CASE



Temperature difference (°C)

Fig. 11-2: test – model correlation final results for the hot case

AVERAGE = 0.33°C **SIGMA = 1.07°C**

The positive average means that the thermal model results are, in average, hotter than the test data for the hot balance This gives an additional conservativeness to the thermal model predictions in hot cases

11.3 HOT + COLD

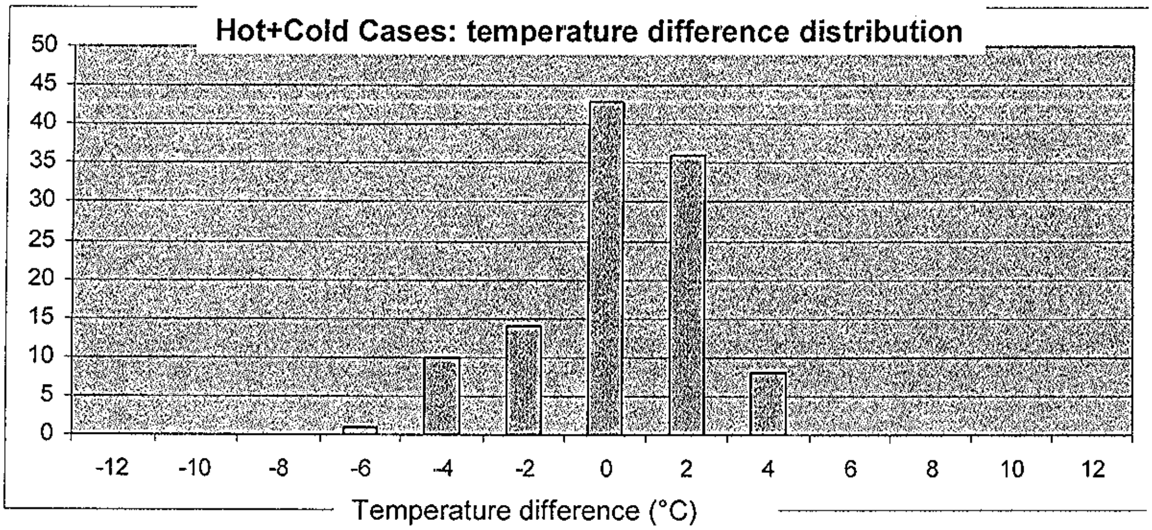


Fig 11-3: test – model correlation final results – both hot and cold case

AVERAGE = -0.68°C **SIGMA = 2.04°C**

Criteria of correlation are satisfied

Moreover, the model predictions are conservative both in hot and in cold cases.

12. FLIGHT PREDICTIONS

After the model has been correlated, the new flight predictions have been generated for a reduced set of cases.

The first step was to re-align the thermal model to the flight configuration; of course, the modifications proper of the test configuration have been abandoned, keeping only the applicable correlation results (see previous sections for further details).

Moreover, the Flight submodels and contributions which were missing in the test (e.g , EIB mechanical frames, harness) were restored.

Finally, a new set of interface data (see RD2, section 6.3 10) has been generated for the ECAL external surfaces. In fact, the AMS-02 system thermal model (which includes the ISS, and all the other AMS-02 detectors) constantly evolves as updates are available, which come from all the subsystems. The interface data used in the RD2 are prior to march 2005; a new set of interface data for the ECAL was generated in December 2006, for the worst hot and worst cold cases for the ECAL. The updates to the new AMS-02 system model, and the new survey of all the orbital cases, lead to a re-definition of the worst cases, which are different in terms of orbital parameters with respect to the previous ones

The worst cases are now characterized by the following beta angle and attitude angles:

	Worst Hot	Worst Cold
Beta Angle	-75°	0°
Yaw	-15°	0°
Pitch	25°	0°
Roll	0°	0°

Tab. 12-1: beta and attitude angles of the worst hot and worst cold orbits

With respect to the results presented in RD2, the new result differ both because of the different [correlated] model, and because of the different orbital external conditions.

The temperature of the ECAL PMT (on which the requirements are set) changes in the following way:

HOT CASE	RD2 (TAR)	Correlated model flight prediction	Delta T
ECAL RAM PMT, average	50.2	49 5	-0 7
ECAL WAKE PMT, average	55 7	53.4	-2.3
ECAL PORT PMT, average	49.9	48 7	-1.2
ECAL STARBOARD PMT, average	59 0	56 5	-2.5
ALL PMT AVERAGE temp.	**53.7**	**52.0**	**-1.7**
ECAL PEAK temperature (MAX)	**59.7**	**57.5**	**-2.2**
COLD CASE			
ECAL RAM PMT, average	-11 6	-10.0	1 6
ECAL WAKE PMT, average	-13 0	-9 9	3 1
ECAL PORT PMT, average	-11 3	-9 2	2 1
ECAL STARBOARD PMT, average	-13 3	-11 2	2 1
ALL PMT AVERAGE temp	**-12.3**	**-10.1**	**2.2**
ECAL PEAK temperature (MIN)	**-14.3**	**-11.9**	**2.4**

Tab 12-2: temperature results for the worst hot and cold cases for the ECAL, before and after the model correlation.

As one can see, all the temperature differences are always below 3.1 °C
Moreover, the new flight prediction temperatures are lower in the hot case, and higher in the cold case.

Therefore, the previous analysis presented in RD2 is confirmed by the new model, with some additional margins. Previous results can be considered a conservative estimation of the on-orbit behavior, both in hot and in cold conditions.

Since the past results are enveloping the latest correlated flight model results, we don't consider necessary to repeat the complete set of analysis cases. Being the requirements fulfilled by the non-correlated model, the conclusion is that all the requirements are still met, with broader margin.

13.CONCLUSIONS

The ECAL thermal control system has been presented. All its components have been described.
The thermal model has been described
The test correlation activities have been presented, and the final result is complying with the correlation requirement of average and variance between model and test.
The correlated model has been described, and the new flight predictions have been run.
The correlated model results are in line with the previous analysis presented in RD 2, and confirm the compliance of the ECAL TCS with its applicable thermal requirements